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NUCLEONICS

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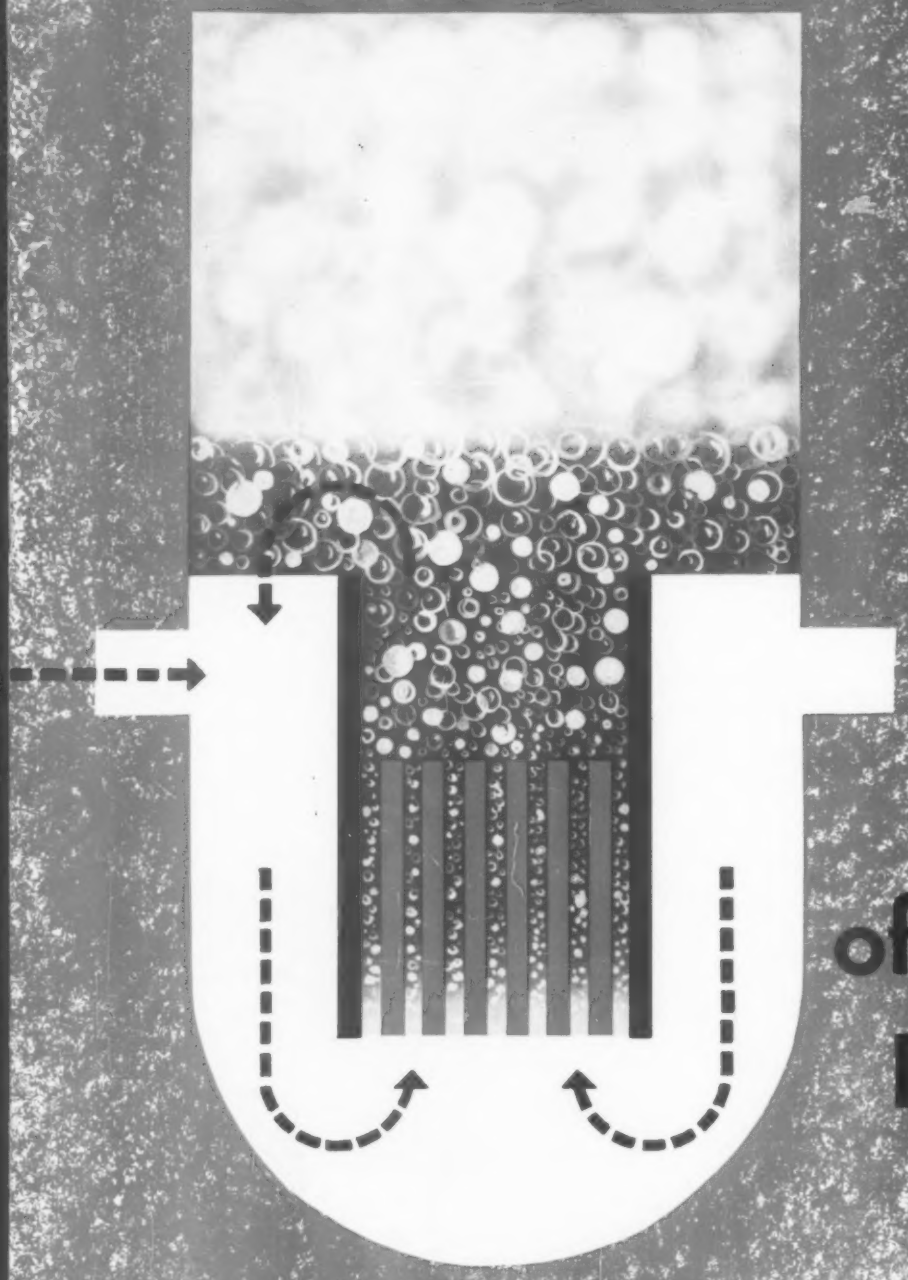

The Future of Boiling Reactors

page 42

Now — Complete Coverage of ALL Power Requirements In The Nuclear Field!

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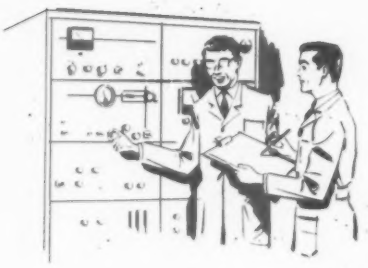

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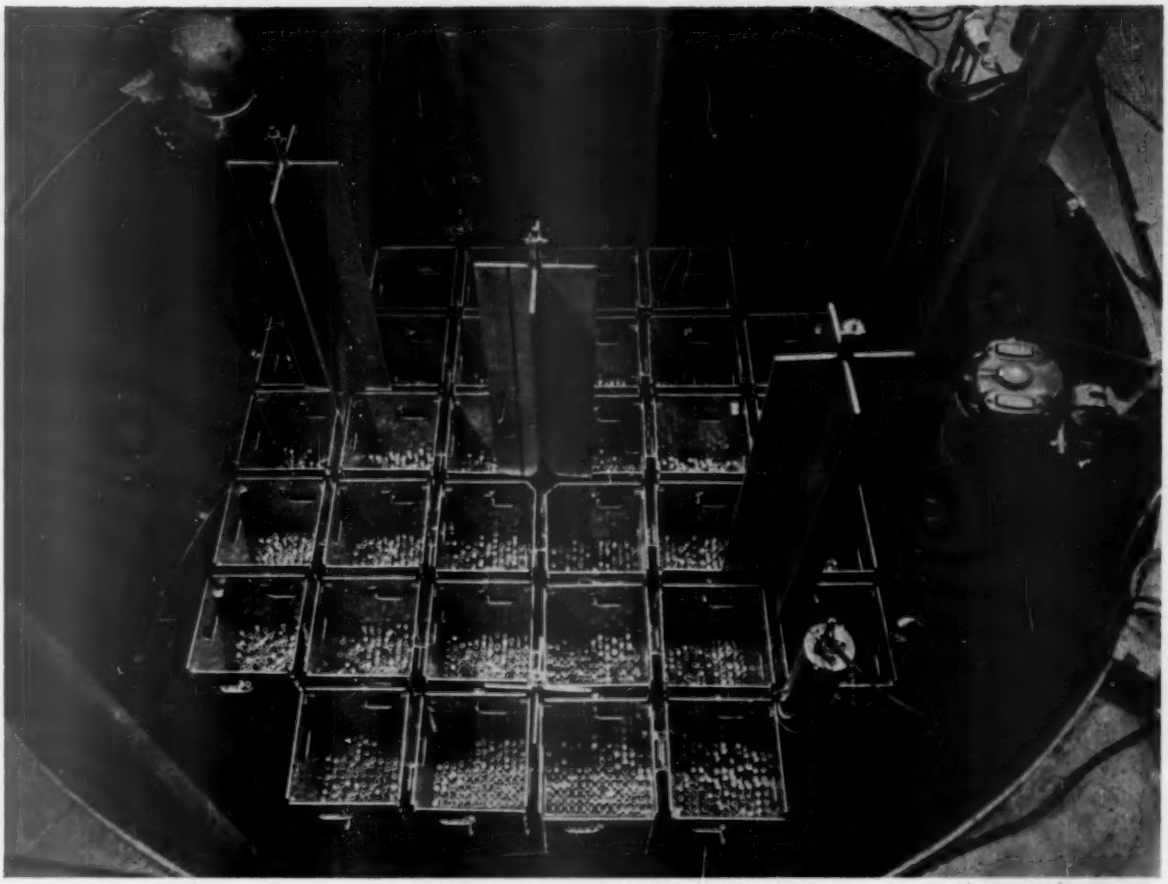

Critical assembly with which B&W physicists are developing the optimum core design for the Nuclear Ship Savannah. Each of the thirty-two sub-assemblies consists of slightly enriched uranium powder swaged into stainless steel tubes.

B&W PROGRESS REPORT:

N.S. SAVANNAH—*Critical Experiments Underway*

The reactor core for the world's first nuclear merchant ship, the N.S. Savannah, is now undergoing final design at Babcock & Wilcox. A test core went critical on February 6, 1958. Experiments are now being run to verify core design calculations of such factors as flux distribution, reactivity and optimum fuel arrangement.

One of B&W's primary objectives is to achieve the longest core life possible with present technology. Present estimates are that a single loading of nuclear fuel will allow the Savannah to steam for 350,000 nautical miles—about 3½ years—based on a lifetime of 600 full power days.

The core design embodies a number of superior features applicable to marine propulsion. For example, fuel elements will contain slightly enriched uranium oxide, which is less subject to distortion under irradiation than is metallic fuel. Since the oxide is almost completely inert to water, hazards due to chemical actions between water and fuel, in the event of fuel element rupture, are reduced. Another significant feature is that the U-238 contained in this fuel will be converted to plutonium, another fissionable fuel, which will supplement the initial U-235.

Concurrent with this series of critical experiments, the reactor vessel, heat exchangers, and pressurizer for the Savannah are being fabricated in B&W's heavy-component facilities.

The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

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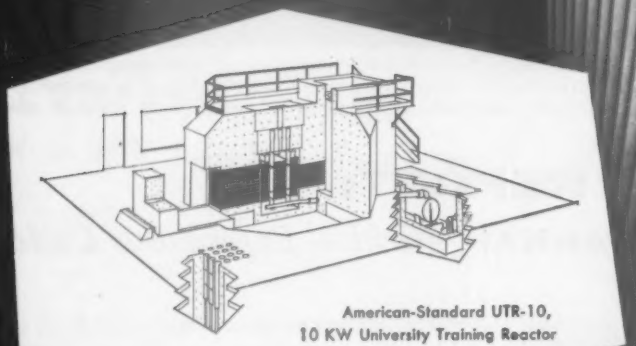

American-Standard UTR-10,
10 KW University Training Reactor

Uranium-Aluminum Fuel Element
Fabricated at M&C Nuclear

Experience at M&C Nuclear, Inc. in the fabrication of uranium-aluminum alloys clad with aluminum allows the low-cost manufacture of these fuel elements to meet the requirements for university training reactors.

The fuel plates shown were produced by M&C Nuclear, Inc. for American Standard, Atomic Energy Division, to be used in their university training reactors.

M&C Nuclear will be pleased to assist you in your experimental programs by supplying information on quality fuel based on your specifications and designs. Write our Manager of Marketing and Contract Administration.

The fuel plates, above, were manufactured to the following dimensions and specifications:

Weight	23 grams U^{235}
Element Length	25.938 ± .015″
Element Width	3.000 ± .015″
Element Thickness	.110 ± .006″
Fuel Thickness	.090″ nominal
Cladding Thickness	.010 ± .002″

Variations of dimensions are possible to meet special requirements.

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About NUCLEONICS

The Earlier Bird

You may have noticed that this issue of NUCLEONICS reached you earlier in the month than past issues have. That's as it should be because, starting with this January, 1959, issue, we have moved our mailing date to the 24th of the month preceding the month of issue rather than the 8th day of the month of issue as had been the case before. Frankly it's a technical requirement that lead us to make the change—Maple Press, the master printers who actually manufacture this product each month, acquired a new press on which we could be scheduled (to mutual advantage) only if we advanced our mailing date. However, we had long wanted to get our magazine to you closer to the first of the month but had been awed by the rescheduling problems it would create for us. Now that it's over it really wasn't too bad. Key ingredient: get the managing editor out of the office for a month-long trip out West (he'll be reporting on the sun-blessed nuclear West from foggy New York in this department next month).

Reprocessing Strategy

There are at least two points of view on the over-all strategy for reprocessing of nuclear reactor fuels. One side says we should have central reprocessing plants to which spent fuel would be shipped from reactors spotted around the country. The other view is that the reprocessing plant should be a small affair directly associated with one or a small group of reactors. To take care of the wide variety of fuel types that exist at present the first group would employ multiple head ends on a common (and generally aqueous) reprocessing line; the advocates of decentralization would handle this problem by tailoring the reprocessing plant to the reactor served.

A reprocessing method that is particularly well suited to small throughputs such as would be associated with single reactors is the pyrometallurgical process. It's been the subject of many design-study articles in NUCLEONICS. This month we carry an article (page 50) that demonstrates that pyroprocessing technology exists on a pilot basis today and correspondingly that a basis exists for realistic costing of such methods.

Past is Prologue

Starting, appropriately enough, with this first issue of a new year, we have included, as you will see at the right, a look back at NUCLEONICS 10 years ago. We feel that an attempt at understanding and appreciating the past is incumbent on each of us, and for the infant, yet fast growing, nuclear industry even a decade provides valuable perspective. And perspective is something we all can use more of—in the press of meeting daily crises the average guy in this business gets precious little of it.

We're proud of the fact that we've been around to report the growth of our nucleonics industry in its formative years and invite you to join us periodically in perusing its past.

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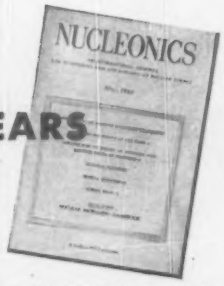
10 YEARS AGO



URANIUM HYDRIDE, a definite compound of composition UH_3, was investigated extensively during Manhattan Project days. With this composition the density of the contained hydrogen alone is 0.14 gm/cm$_3$, about twice that in liquid hydrogen itself. The emphasis in this early work was on a broad understanding of the properties of UH_3 and an almost free-wheeling exploration of how it might be used—as a laboratory source of pure hydrogen or deuterium, how hydriding could aid in the elimination of intermetallic compounds of U, and whether the system UH_3 could be used for separating deuterium from hydrogen (no efficient technique could be found). Use of UH_3 as a fuel is hampered by its relatively high dissociation pressure, (1 atm at 400° C.) *F. H. Spedding, et al., NUCLEONICS Jan '49, p. 4, Feb. p. 17, Mar. p. 43.*

PHOTOMULTIPLIERS were new tools in the nuclear physics laboratory in 1949, which was the year 2 of modern scintillation counting, Kallmann's pioneering work on naphthalene scintillators having been published in July, 1947. There has been a steady improvement in design, but the considerations discussed in 1949 are pertinent today. *G. A. Morton and J. A. Mitchell NUCLEONICS Jan. '49, p. 16.*

Next Month

Army Reactor Program

Reactors on the Line, No. 7—Argonne Low Power Reactor

Method for Estimating Beta-Counting Efficiencies
By B. P. Bayhurst and R. J. Prestwood, *Los Alamos*

How Safe Should Reactors Be?
By Ernest Siddall, *AECL, Chalk River, Canada*

Later Months

SENN Reactor

Fabrication of Borax-IV Fuel
By J. H. Handwerk, *Argonne National Laboratory*

Special Report on Nuclear Instrumentation

Containment—A Review

Leaders of the Mallory-Sharon technical team *(L. to r.) Lee S. Busch, Technical Director; Frank H. Vandenburgh, President; Graham B. Brown, Vice President, Marketing; Dan E. Cribbs, General Manager, Wrought Products Division.*

Take a new look at this

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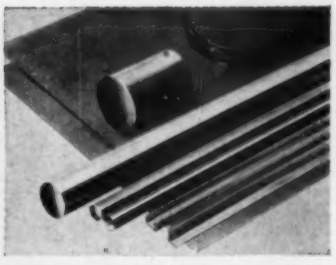
Sponge Production—*Zirconium tetrachloride, delivered in these huge 6-ton rubber containers, is processed into zirconium sponge or platelets at Mallory-Sharon's modern sponge plant in Ashtabula, Ohio.*



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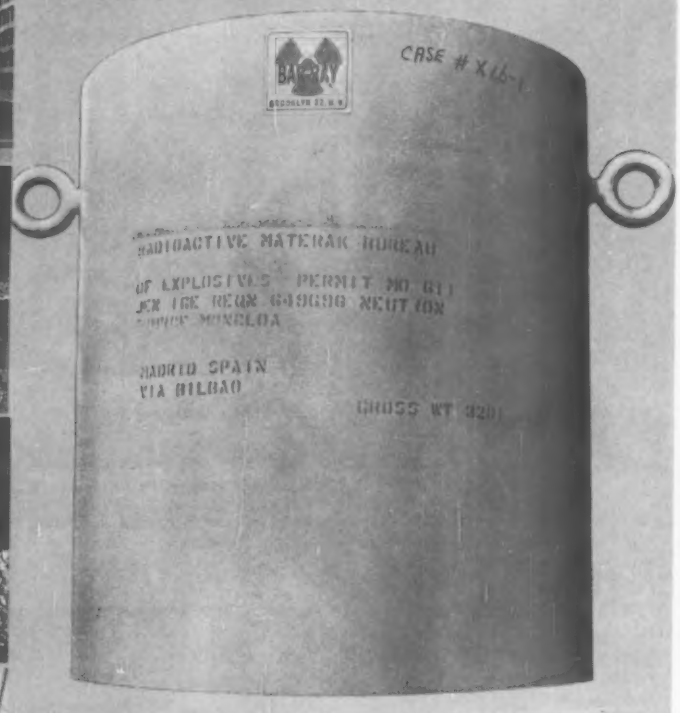

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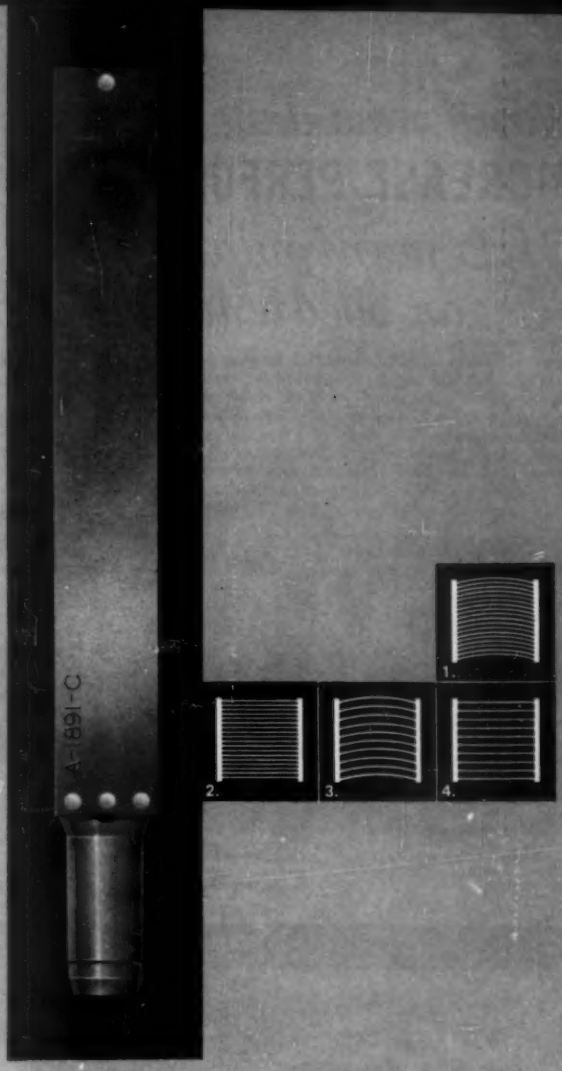

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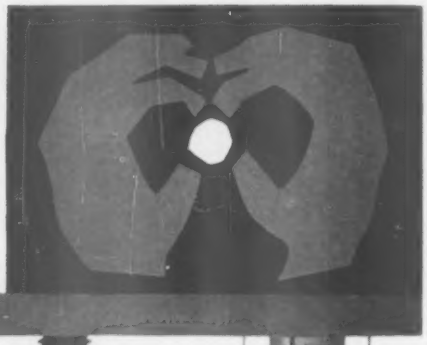

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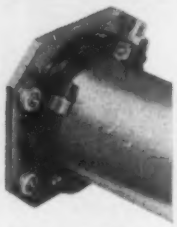

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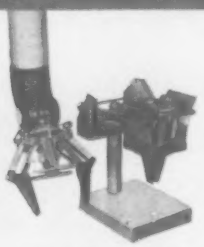
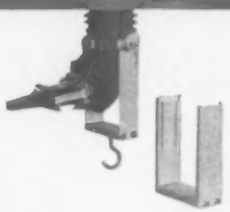
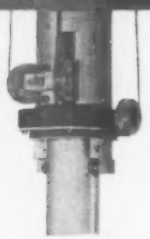


Improved *wrist joint, tong,* and *tong jig:* Greater protection of gears, more rugged, easier interchange.

Improved *handle:* More rugged, more satisfactory control of separation indexing and squeeze motion lock.



Improved *booting* and *load hook: Partial or* complete booting possible, load hook fits on booted or unbooted MTRL.



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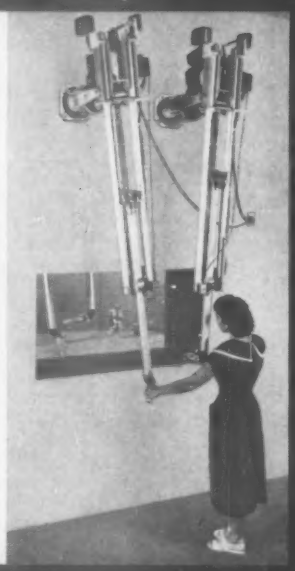
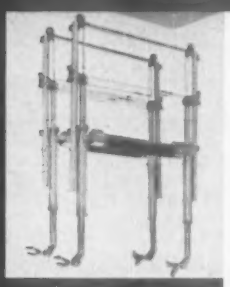
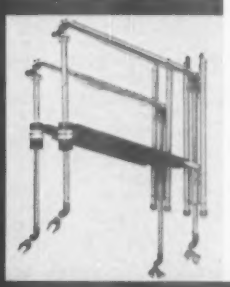




for over-wall installation

CRL MODEL 4

General purpose — for installation over a barrier wall or through ceiling opening of protective enclosure.



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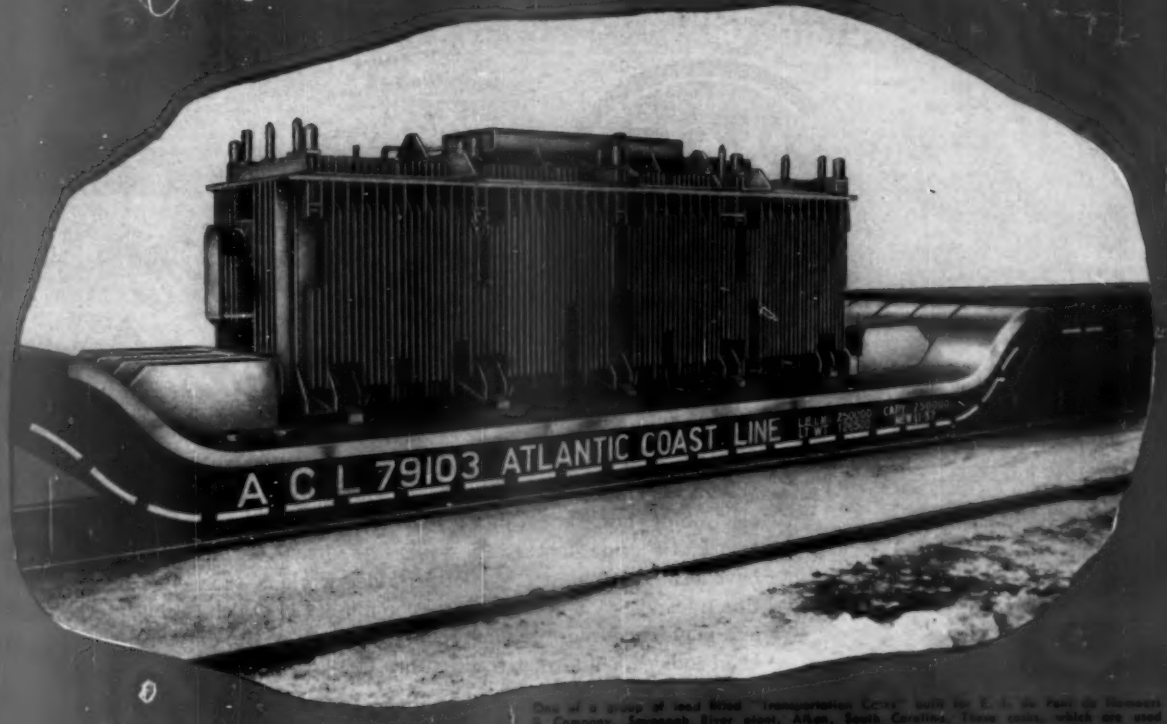

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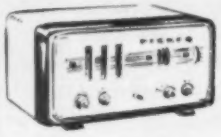

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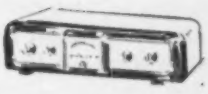

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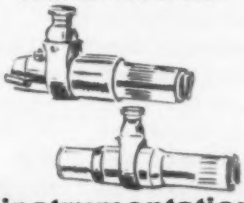

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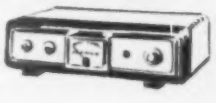

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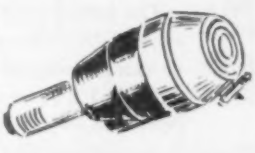

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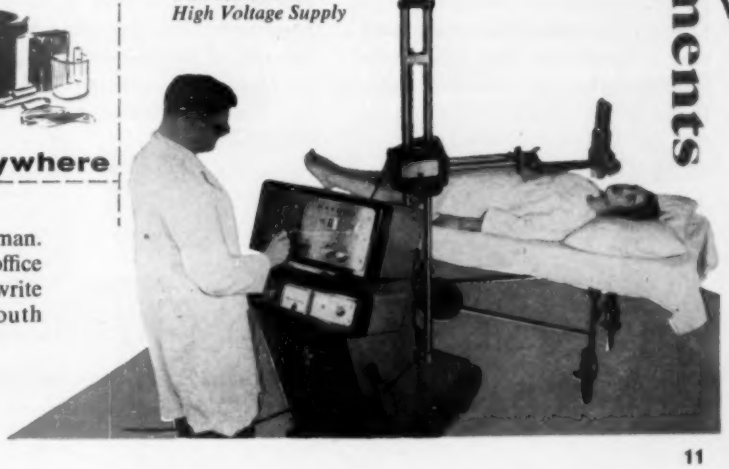

PICKER nuclear instruments

Thorium . . . a Superior Fertile Material

Now used more and more in nuclear power plants

a report by LINDSAY

There are good reasons for the increasing attention being given to thorium as a fertile material for nuclear power plants. Most important, U^{233} has a higher η than either U^{235} or Pu for neutrons of thermal energies and just above. Of all the thermal fuel cycles, that using thorium and U^{233} offers by far the best possibility of breeding, or at least achieving high conversion ratios. Obviously, the amount of excess reactivity required for a given fuel lifetime decreases and fuel costs become much lower as the conversion ratio approaches 1.0.

Another factor not often mentioned, but quite important, is that as the conversion ratio approaches unity, the distribution of power in the core becomes more constant throughout the life of the reactor. Therefore, it may be practical to design a core to operate at maximum power, by orificing each cooling channel for maximum power level at the start of a core life, without fear of a subsequent shift in the max/ave heat flux as fuel is consumed near the center of the reactor.

THORIUM ADVANTAGES

Thorium's physical properties also give it an advantage over uranium. First, the metal can withstand much higher temperatures than uranium metal since there is no crystalline transition at moderate temperatures. Then, too, thorium has a somewhat higher thermal conductivity than uranium, so that on two counts, it can experience a higher heat flux. Furthermore, experiments to date indicate that thorium-based fuels are considerably more resistant to radiation damage than their uranium metal counterparts. Although uranium fuels are much more fully developed than thorium-uranium fuels, three domestic experimental reactors are experimenting with the thorium base fuel, and four full scale reactors are either using or planning to use the thorium-uranium cycle.

The major problem confronting Th-U^{233} enthusiasts is the fact that the uranium produced is contaminated with U^{232}, which decays on a 74 year half life to Th^{228}, which in turn decays on a 1.9 year half life to a long chain of short half life daughters, some of which emit extremely hard gammas. Thus, both fuel and fertile material are contaminated, making recycling a bit more complex than it would otherwise be.

The fertile material, in order to be recycled, would have to either be stored for a long cooling off period, or remotely fabricated. The fuel would have to be fabricated very shortly after processing to remove any Th^{228} which may have built up, or it would have to be remotely fabricated too. And since most elements use a mixture of fuel and fertile material, if either required remote fabrication, both would. In any event, it seems that shipping and subsequent handling of the fuel would have to be by remote means, since Th^{228} would continue to be produced as the result of U^{232} decay.

Although the Th-U^{233} cycle has most attractive nuclear and metallurgical properties, the cycle's fuel fabrication costs per element appear to be inherently more expensive than for other cycles. However, we are hopeful that this higher cost of fabrication will prove to be of small consequence when considered in light of increased fuel element and core lifetime, higher permissible specific power levels, and superior neutron economy.

PLUTONIUM PREMIUM

Until now, there has been considerable emphasis throughout most of the world upon the by-product production of plutonium from power reactors. Naturally we have been eagerly looking forward to the day when there would be no premium placed upon plutonium production. Now we seem to be approaching a situation in which truly peaceful application of nuclear power is feasible so that at last the thorium-uranium cycle should receive the consideration it deserves on its technical merits.

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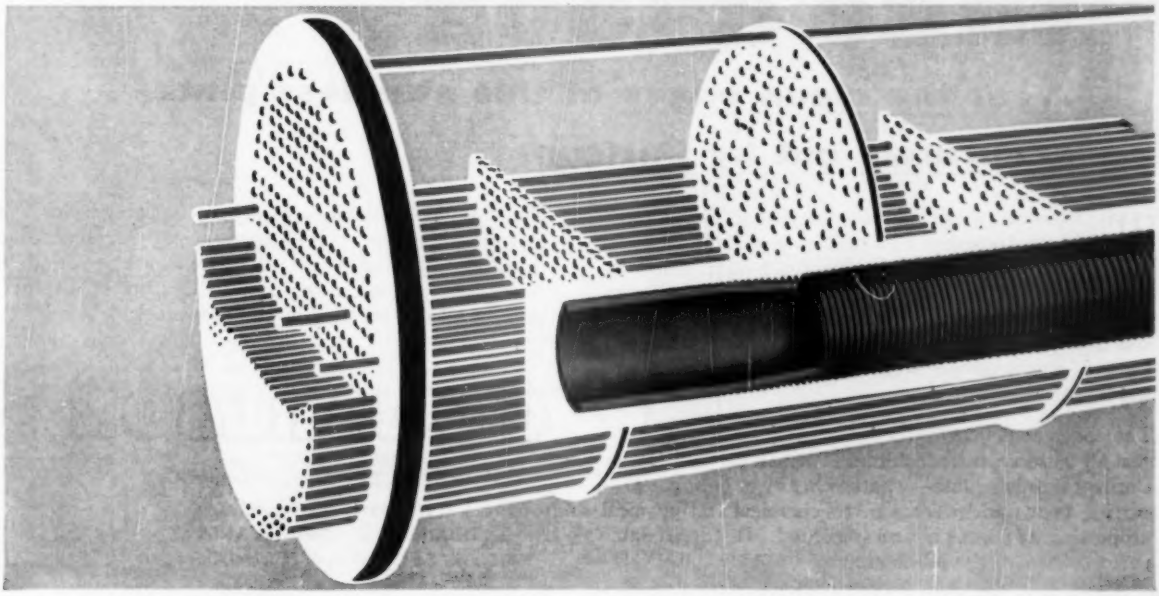

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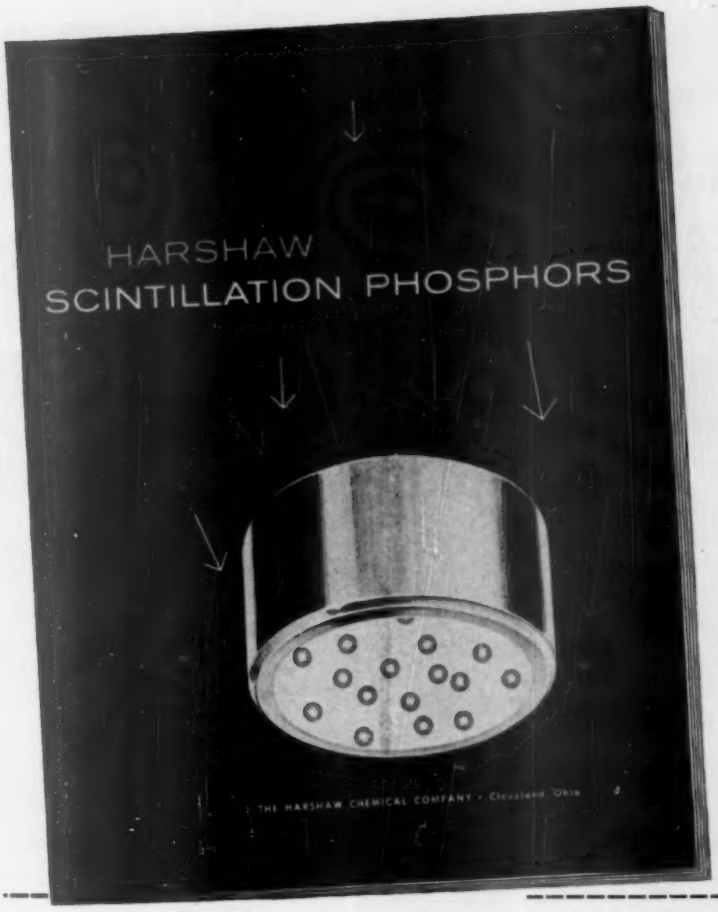

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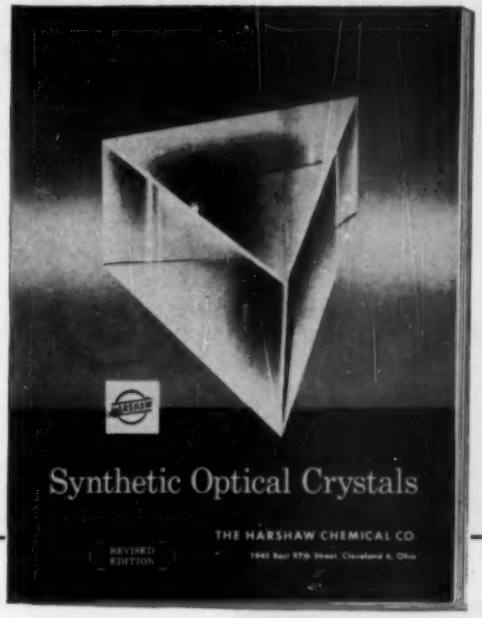

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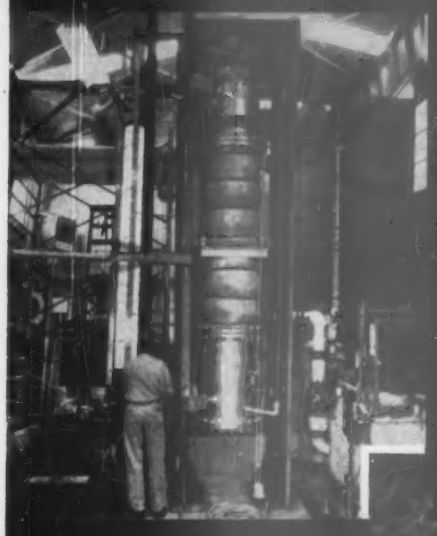

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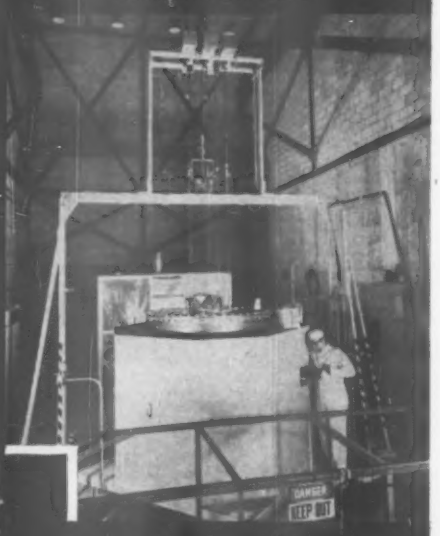

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ROUNDUP of Key Developments in Atomic Energy

Nuclear Activity Burgeoning the World Around

To start off the new year, NUCLEONICS' Roundup section presents vignettes of quickening world atomic activity. It opens with a NUCLEONICS *reporter's account of the British governmental program, and continues with reports by Roundup's world-wide network of correspondents on developments in Germany, Japan, and Red China.*

Nowhere in Europe is there so much to see—in the nuclear sense—as in Britain.

Americans are, of course, accustomed to hearing that the difference between their atomic program and that of their British cousins is the difference between pushing ahead on a broad, varied front, and a narrow thrust concentrated on a single, all-eggs-in-one-basket concept. Like most generalizations, this is as misleading as it is basically true. One cannot appreciate the magnitude of the British effort until one has criss-crossed that country, smaller than the state of Oregon, and seen Harwell with more research reactors than Oak Ridge and Argonne combined, now overflowing to a new site at Winfrith Heath; seen the British national reactor testing station at Dounreay (in remotest, bleakest Scotland yet only 3¼ airline hours from London); seen Calder Hall and the four almost incredibly huge civil stations (with Chapel Cross, 1,731 Mw(e) total installed capacity—more than twice the 749 Mw(e) total of PWR, Dresden, Indian Point, Fermi and Yankee); seen the scale of the development labs of the four industrial groups and the dedication of their people.

Whatever disadvantages the single-concept program may have—and the British are the first to admit these, and to bemoan the implacable budget that forces specialization upon them—it does contribute greatly (along with the visibly-approaching power shortage) to lend a direction and a purposefulness to the British program that has long been lacking in the U. S. The British know where they're going, and know rather precisely what they have to do to get there, and by what choice of routes. And the specialization on gas-cooled reactors is not so rigid as to prevent their taking out insurance against failure of advanced gas-cooled systems, covering their bets with work on heavy-water cooling and now probably boiling water as well.

Three successive stages of development beyond the four first civil stations are now under simultaneous development. First is the Trawsfynydd,* or second, generation of civil stations, on which the industrial groups are now feverishly preparing their highly-competitive bids. These will not be radically different from the first-generation stations. In fact, the first two second-round plants, Trawsfynydd and "Kent A" at Dungeness,† were deliberately made the same size—500 Mw(e)—as the last one of the first round, Hinkley Point, in order to see how much the engineering could be improved without going to a completely different design (which is what would necessarily result if one increased station capacity by 100–200 Mw). Moreover, whereas Trawsfynydd is limited in size by the amount of cooling water available—by the amount of heat that can be put back into the reservoir, Dungeness on the English Channel is not; and since colder condenser water will always yield greater steam output, Dungeness will have 550-Mw(e) output from the same size reactor. This will permit the exercise of designing two reactors equal in size but optimized for quite different site conditions.

The third second-generation station, now set for Sizewell on the North Sea coast in Suffolk, will be 650 Mw(e), but is at present still expected to be a natural-uranium-fueled plant. Completion of Sizewell carries the program up to 1964, brings the total installed nuclear capacity in Britain to 3,431 Mw(e), and carries to the next stage, now already under development: AGR.

The Advanced Gas-cooled Reactor is one of the forward-looking designs on which Britain is staking much. As those who saw the models exhibited at Geneva know, AGR is beryllium- instead of magnesium-canned, and uses 1.4% enriched uranium oxide of the highest possible density (NU, Sept. '58, 78). AGR is mainly a step forward in metallurgy, according to Sir Leonard Owen, head of the UKAEA's Industrial Group. It is being tried out in a 100-Mw(th), 32 gross, 28.5 net Mw(e) size at Windscale on the very site of the No. 3 plutonium production reactor which never went beyond the foundation stage; new foundations for AGR are now being started, and construction contracts have been let (NU, Dec. '58, 26). But the AGR system will not be proved out until 1962, Sir Leonard points out—this includes one year's operation—and so the last round of reactors in the ten-year White Paper campaign, those going on the line in 1965–66, are the first that one can expect to use "the new metallurgy." If AGR fulfills its promise, he says, it will be only 50% higher in cost than coal-burning stations, as against the first-round nuclear stations, 200% higher. Meanwhile the heat rating will be going up: where Calder gets only 1 Mw heat from 1 ton of fuel, and the first civil stations 2.2 Mw, AGR is expected to yield 5, 6 or more Mw/ton.

Commercial-size AGRs are counted on to carry Britain through 1970 with economic power, but after that another quantum jump in lower cost and greater efficiency is sought. To that end the British are pushing the HTGC (High Temperature Gas-Cooled reactor), furthest development of reactors depending on gas for heat extraction; and the fast breeder.

HTGC, in which the high temperatures will be made possible by cladding the fuel in impermeable graphite, is also the subject of a development project already in construction—in this case, owing to the more advanced nature of the reactor, a zero energy unit is being built first, at Winfrith Heath (NU, Sept. '57, 31). This is scheduled to be completed this summer, and will be followed by a 10-Mw(th) engineering test of the concept, which may be built and operated in collaboration with OEEC's European Nuclear Energy Agency. HTGC is entirely the baby of the Research Group, and is an exception in this regard; generally the research

* The closest a non-Welsh tongue can seem to come to pronouncing this is "Trawvaneth."

† This site has space reserved for a later station, Kent B, not yet planned for.

staffs at Harwell do the theoretical and laboratory research work, then turn the results over to the Industrial Group at Risley for engineering design and construction.

The other long-range program, the fast breeder, is of course approaching a climactic stage: startup of the big 15-Mw(e) pilot plant at Dounreay, which may come any time this spring.

Despite comments on AEC's last annual report interpreting one paragraph as mirroring a slackening of enthusiasm and effort on the fast breeder concept, no evidence of any disenchantment with the concept was encountered anywhere in AEA country. Sir Leonard Owen explained that one real headache to leaders of Britain's atomic energy program has been the need to push forward so fast.

"Atomic energy is going ahead much faster than anything has ever gone before: is it going too fast?" he asks. "When you are in the middle of a power program as we are, you have to give due thought to economy, safety and reliability." Calder Hall was built on a crash-program basis, the first-round civil stations on as tight a schedule. With commercial-size fast breeders not required on the line until 1970, here at last is one opportunity to develop one reactor concept thoroughly from the ground up, as it ought to be done, without skipping stages to meet deadlines, Sir Leonard feels. (This also explains why the fast breeder's lower priority led to it being chosen to supply scientists for the post-Windscale investigation—one of the circumstances that led to the rumors that the fast breeder was being phased out.)

"My thinking," Sir Leonard remarks, "—and [Sir John] Cockcroft doesn't agree—is that you want two reactors to burn a given quantity of uranium efficiently: a thermal reactor, and one to burn its by-products. You can't get optimum burning of one pound of uranium in one reactor. One way of burning the plutonium is in a fast reactor—there are others. If the fast reactor comes off, it will be a very cheap machine indeed—the cost would really bump down. It offers fantastic heat-transfer conditions; in fact the strain it puts on metallurgy is quite a problem. Next year will give us quite a bit of experience. If it comes off, it will be at least as cheap as coal."

Interestingly, Risley sees the fast breeder as a reactor type basically low in capital cost. The Industrial Group people point out that although the fast breeder "will always be a complex machine, more expensive than if we knew how to build it as a simple machine," its size, hence foundations and civil work, are smaller than the gigantic gas-cooled plants Britain is now building. Also the heat exchangers can be improved: where copper interlining is now being used, Risley hopes for development of an ordinary shell-and-tube sodium-to-water heat exchanger. Another factor is that pumping liquid sodium, complicated though it may be, does not take as much power as it does in gas-cooled reactors where as much as 10% of the electricity produced goes back into powering the blowers.

Once they have taken the fast breeder to criticality, its builders are going to spend a long period in low-power operation through 1959, assessing performance, and will only then map a detailed experimental program, Dounreay's personable and popular director, Robert Hurst, indicated. However one thing already planned is to change to a plutonium core in the early 1960's, after considerable modifications have been made in the first core. Individual Pu samples will be put into the first core from the start, and will be increased. The chemistry research section is already studying the reprocessing of Pu fuel elements; and although ground was not yet broken in October, a pilot plant for Pu-fuel reprocessing will be completed by the end of this year.

The first core has been modified somewhat in the light of EBR-1 experience. Dounreay was always designed so that flow could be controlled in case of a "melt-out," with collection of a critical mass of melted fuel being avoided by using deflector plates and catch-boxes below the core. It has been felt that an EBR-1 meltdown could not occur at Dounreay because there is no series flow in the coolant. However the catch-box could be attacked, so a second series of about 24 catch-boxes and deflector plates was installed below. Also, in view of what was learned in Idaho about bowing, the Dounreay core has been made much more rigid. "But we do not accept the possibility of a melt-out," Dounreay leaders say. "We must be satisfied with the core design [that they do not permit of meltdown]."

The exchange of information agreement with the Detroit fast breeder group will be of exceptionally great mutual benefit, Hurst believes, because the timing dovetails: "they can get early data on our small machine, then we on their big one." The latter data will aid in the decision whether or not to proceed with plans to build a full-scale prototype fast-breeder power plant at Dounreay in the mid-1960's.

Originally set up just for the first breeder program, the Dounreay Experimental Reactor Establishment now has a much broader mission. Intended for 1,400, there are already more than 1,700 staff—350 of them scientists—working at this legendarily fog-bound, storm-ridden inhospitable coast which on at least one October's day proved it could be as sunny and smiling as the Mediterranean littoral. In addition, there is also on the premises—but organizationally independent—an Admiralty group building a land-based prototype of the first British-designed nuclear submarine reactor.

Dounreay is not only building the fast breeder, but will handle the entire cycle: it will make the fuel, inspect the spent fuel in its hot cells, and reprocess it. It has very close relations with the other stations of the Industrial Group, doing irradiations for them and farming out work to them; it is also helping Harwell with studies on uranium swelling and on irradiation behavior of oxide for AGR.

Full House at Harwell

Harwell, in its turn, has limited its own fast reactor work now solely to doing calculations for Dounreay. This first fountainhead of British nuclear research, now fully expanded to 6,000 staff and able to accommodate no more, also finds itself doing a good deal of support work for the civil stations ("these are firm commitments—those stations *have* to work"). Among studies in hand in the reactor division are measurements of effective cross section; difference in effective eta values between U-235 and Pu; analysis of fuel irradiated at Calder and Windscale, and measurement of fission product buildup and their cross sections; reactor physics work on oxide fuel clusters for AGR; design of the zero-energy HTGC; a start on physics work for the Gas-Cooled Deuterium Reactor, an alternate project to back up the advanced graphite-moderated systems. The division is also working with light-water moderated reactors for the naval program, operates the materials-testing reactors Dido and Pluto, studies their physics to learn to predict flux depressions due to experiments, in addition to the usual gamut of studies on shielding, neutron spectrum, heat-exchange, slurry technology, etc.

JAPAN'S SECOND reactor, the CP-5-type research unit being built by AMF Atomics, is nearing completion

Cockcroft Saves Day for Calder Sale in Japan; Decision Due This Spring

TOKYO

Sir John Cockcroft, a member of Britain's Atomic Energy Authority, with what one Japanese manufacturer called "the artistic precision of a fine English film," last month [November] toured Japanese atomic circles. His "performance" seems to have swept away developing opposition to Japanese purchase of a Calder Hall reactor as this country's first atomic power producer.

Top government officials, who already committed themselves to a British reactor last year, said he eased any doubts they had about Calder's safety features, burnup time for fuel, and negative temperature coefficient. Cockcroft's public lecture, a mixture of British understatement and urbanity, helped persuade the few remaining holdouts in the Japanese public that atomic power is a good thing.

Thus it now looks as though a decision will be made among the three British bidders by early this year—certainly by spring. That puts the whole program about six months behind schedule—but not less than most observers had expected when it took shape late last year.

Utility companies, particularly, are champing at the bit. They want the Calder-type reactor built and out of the way. There is increasing pressure from them to abandon the government-sponsored Japan Atomic Power Company [JAPCO] which originally had been designated as the vehicle for the entire nuclear power program. Chances are the Calder-type will be built by JAPCO, and future plants will be built either by the nine major utilities themselves or in combination, or under the auspices of the government and the Utilities Electric Power Development Corporation [DENPATSU].

Manufacturers, too, are taking the attitude that while the Calder-type is not the reactor they wanted, the government is committed, and the Calder will provide a training ground for technicians for future reactor projects.

Decision Due on Builder

The government is now juggling the decision as to which British contractor will get the project and which local company will subcontract to assemble parts and build some elements in Japan.

Hitachi is believed to have the inside track. It is linked with the English Electric–Babcock & Wilcox group. But Fuji Denki, an electrical equipment company which in the past has been primarily a light electric equipment maker, is now trying to break into the big time and is allied with Britain's General Electric Co. which may be the low bidder. The third entry is the AEI–John Thompson group tied up with both Mitsubishi and Toshiba as local contractors. Since Mitsubishi is now completing work on JRR-2—the Japan Atomic Energy Research Institute's second research reactor subcontracted from American Machine & Foundry—it is believed Hitachi–EEC may get the nod. The whole situation has become so political that Tokyo wags are calling the Calder project the "political demonstration reactor."

U. S. Demonstration Reactor

An equally complicated battle is being waged over the first power demonstration reactor for JAERI. All American bidders have been eliminated except General Electric and Westinghouse. The Japanese tend to think of GE as a BWR producer and Westinghouse as a PWR maker. Therefore the decision will depend partially on the decision whether to spend a larger sum to buy a PWR. Mitsubishi, with historic ties with Westinghouse, will be its subcontractor. GE's subcontractor is still unresolved: Hitachi, which has a license for GE turbine-generators, and Tokyo Shibaura, which is 12% owned by GE, both want the project. A plan is probably afoot to use both as subcontractors if GE should get the nod from JAERI for a BWR.

Meanwhile there is continuing study on several research reactor projects. Kyoto University wants a reactor but the manufacturers claim too many professors are spoiling the broth and trying to get an impossible all-purpose reactor. St. Paul's [Rikkyo] University will get a General Dynamics Triga reactor as a gift from American Episcopalians and has found an isolated spot—a former American military installation near Yokohama. One reactor for Kansai [the area around Osaka] has been approved by the government and several American companies are bidding. But several sites have been found wanting or the local population has refused to allow the project. Musashi Technological College and Tokai University, both in the Tokyo area, have reactor plans but financing and sites have not jelled.

The Japan Atomic Industrial Forum has approved a plan for an experimental nuclear-powered ship in which all atomic energy groups, shipbuilders, and the government would participate. Because of Japan's position as a major shipbuilder there is a general feeling that something ought to be done to push the maritime project—and in fact the JAERI power demonstrator reactor was originally planned to include maritime applications, although this expensive feature is now in doubt. But the shipbuilders are dragging their feet, and about the only way the project will get off the ground is if the government digs up an estimated ¥100-million [$260,000] needed to launch it. There is not much chance of that—at least until the power reactor program is well underway.

German Power Plans in Wait-See Phase; Liability, Euratom, Cost are Problems

BONN

German power reactor plans seem to have reached a wait-and-see phase. Little progress has been made toward a concrete start on the power reactor program announced in November 1957 by the Atomics Ministry calling for construction of four or five German-designed power reactors of 100–150 Mw(e) each by 1965 (NU, Dec. '57, 26). Uncertainty over the effects of the U. S.-Euratom program and over the liability problem, lack of progress on cost-cutting as reported at Geneva, and a brighter coal outlook all appear to play a part in this situation.

Actually, the only construction order given so far is the one placed by the utility RWE with the manufacturer AEG for a 15-Mw(e) boiling reactor at Kahl near Frankfurt (NU, July '58, 26; Nov., 25). Cost of the project, which AEG is building in cooperation with General Electric and the construction firm Hochtief AG., Essen, will be approximately $8-million.

The preliminary design order which the public utility group AVR had placed with a team consisting of Brown, Boveri & Co. and Fried. Krupp is completed. Everything seemed to be ready this summer for starting construction at the fixed site at Jülich, the North-Rhine–Westphalian nuclear research center (NU, Aug. '58, 26) but the expected construction order for a 15-Mw(e) neon-cooled pebble-bed reactor failed to materialize and has been delayed ever since.

So has the order for a 100–150-Mw reactor which the Baden-Württemberg group AKS has been expected to place any moment during the last two months. This group seems the only one in Germany planning to skip the pilot plant stage but to go the whole hog right away by ordering what will be Germany's first full-fledged power reactor. The decision is believed to lie between the boiling water, organic moderated and Calder Hall types.

The next to order (after AKS) may be the north-west group SKW, which has also announced plans for a 100–150-Mw(e) reactor. Although SKW is reportedly negotiating with foreign firms as well, German industry hopes that the group will decide for a German design.

Early in December SKW placed preliminary design orders for "large" power plants, thought to be about 150 Mw(e), with AEG and Deutsche Babcock & Wilcox. The orders are valued at about $3-million, of which the governments will bear two-thirds. Decision on a construction order will come in two years when the preliminary designs are done.

No big order is very likely to come from the Bavarian group in the near future. Its most prominent member, Bayernwerk A.G., in Munich, has joined the firm that will operate the RWE pilot reactor (NU, Dec. '58, 26). This seems to indicate that Bayernwerk—and the whole Bavarian group—do not plan to build their own small power reactor and that a full-scale reactor will be ordered only after sufficient practical experience has been gained during operation of the Kahl reactor.

Bayernwerk's partner in this project, RWE, claims that it is still pursuing plans for a 250-Mw(e) reactor in addition to the 15-Mw(e) plant now ordered, but insists that reactor construction and operation costs would have to be competitive with conventional power plants, and it is not likely that they will receive such an offer soon.

Unless the speed of development picks up rapidly, it seems doubtful whether the four-to-five power reactors with a total capacity of 500 Mw(e) called for in the German reactor program will actually be in operation by 1965. And previous hopes that the Euratom-U. S. agreement would bring the number of German nuclear power projects up to seven seem to be less likely still to be realized. True, the advantages offered by this agreement, which have strongly reinforced the position of U. S. firms vis-a-vis German suppliers, may lead to some reactor orders from the U. S. But such orders will probably reduce those for German-designed reactors rather than adding new names to the list of projects planned in Germany. Incidentally, the competition between German and U. S. firms is alleviated somewhat by the fact that most German companies in the nuclear field have cooperation and/or license agreements with U. S. firms and are therefore likely to get a slice of the cake in any case.

Reason for Diffidence

The hesitancy of German utility groups to order power reactors is due to several factors. The major one is the higher construction (about $300/kw) and operating cost of reactors compared to conventional power plants; the Geneva conference has confirmed their opinion that reactors will continue to be uneconomic in the near future.

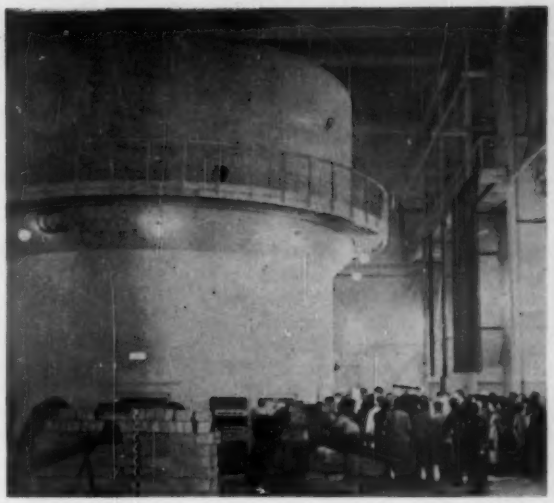
This handicap could be overcome only by governmental assistance. The German Atomics Commission has recently suggested a new scheme whereby the government would shoulder 50% of the cost for preliminary design orders and would—if the company in question cannot raise enough money on the capital market—grant credit guarantees or even give credits for financing the construction order (NU, Nov. '58, 26). Additionally, the government would share the operational risk by covering a part of the losses during operation. This last clause may strongly promote industry's inclination to venture into the establishment of power reactors, but so far, the details on governmental participation in operational losses have not been worked out.

Another reason, though of less importance, is the lack of a federal atomics law. A draft prepared with the consent of all parties in 1957 was torpedoed at the last minute (NU, July '57, 19).

In order to facilitate operation of those research reactors already under construction, most German states have passed brief atomic laws; these, however, are hardly sufficient for power reactors. A new federal law has now passed the cabinet and, after passing parliament, may come into force this spring or summer. The present uncertainty about the legal situation, especially with regard to liability regulations, may also induce utility groups to postpone their orders.

Last but not least, the development of the German energy situation is not very encouraging for nuclear power at the moment. For years, Europe had been able to meet energy demands only with the help of U. S. imported coal. This situation has reversed drastically since the beginning of this year. There are 12-million tons of pithead coal stocks in Germany and the amount continues to grow. German coal mines are turning to the public utility companies asking for long-term delivery contracts. The official energy forecasts predicting steady increases in energy demand averaging about 3% annually have suddenly proved wrong: German energy consumption this year will probably show a 1.4% decline below 1957, and energy exports an 8.8% decline. Yet there is no doubt that energy demand will increase again.

CHINESE VICE PREMIER and Foreign Minister Chen Yi cuts the ribbon at the inauguration of China's first reactor on Sept. 27; Soviet delegate Efremov is at Yi's left



REACTOR (right) is a 10-Mw scale-up of the circular-pool type sold by Russia to her East European satellites (cutaway diagram NU, April '56, 19; photos NU, Sept. '57, 24)

Red China Claims to be Firmly in Atomic Age

(The following dispatch came to NUCLEONICS from Peiping by way of New Zealand.)

Red China now claims that she is "firmly in the atomic age." This follows the commissioning, last September, after about three months of operation, of the country's first reactor and first cyclotron.

These installations, located at the Atomic Research Institute near Peiping, were built with important Soviet assistance. The Russians not only helped to train Chinese scientists and technicians and supplied complete sets of equipment for the reactor, but also provided experts to supervise installation and operation. Heading the Russian team was D. V. Efremov, deputy-director of the U.S.S.R. Bureau for the Utilization of Atomic Energy.

The reactor is of the heavy water type. Its thermal ranges from 7 to 10 megawatts and it is being used for research work. It has also produced 33 kinds of radioisotopes, including cobalt-60, sodium-24, phosphorus-32 and calcium-45. But most important of all, the Chinese say, it is being used to train key scientific and technical personnel in the designing, installation and maintenance of the various types of reactors China plans to build.

The cyclotron is claimed to be one of the most up to date of its kind. It can accelerate alpha particles to energies of 25 Mev.

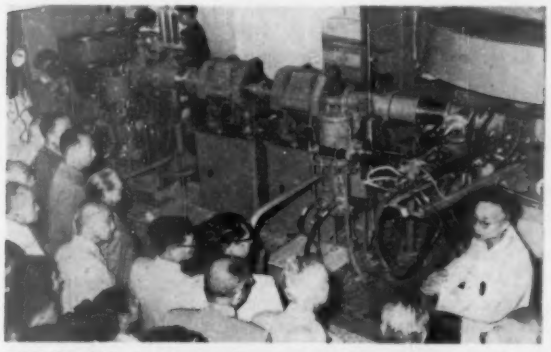
A pressurized electrostatic accelerator built by Chinese scientists and engineers and technicians was also completed some months ago and is now in use for experiments.* It can accelerate protons whose energy can reach 2.5 million electron volts.

The country's first computer is now in operation at the computation institute of the Chinese Academy of Sciences in Peiping. The Institute is using the computer for short-range weather prediction, nonsteady flows, geodetic problems, analysis of stress in the designing of dams, and problems of atomic energy and aerodynamics.

Considering that she entered the field less than a decade ago, China has made impressive progress in nuclear physics. In 1949, when the civil war on the mainland ended, only two rooms were allotted by the Chinese Academy of Sciences for research work in atomic energy. Today the institute of atomic energy is one of the largest research bodies, with a staff exceeding that of the entire Academy 10 years ago.

The study of cosmic rays and isotopes is reportedly making big

* It seems likely that this is a Van de Graaff-type accelerator like one that was part of the Russian scientific exhibition at Geneva '58. High Voltage Corp. engineers who inspected the Geneva exhibit said it was a faithful copy of one of their earlier machines, complete with a unique overdesign.



CYCLOTRON, inaugurated on same day as reactor, is explained to Chinese and foreign guests. Second from left in front row is Vice Premier Nieh Jung-chen, head of the Science Development Planning Committee

COMPUTER is first built in China. Small universal electronic digital computer, located at Academy of Sciences, Peiping, has 4,000 germanium diodes, 800 electron tubes. Photo shows it in operation

strides forward in China. Radioactive isotopes are being used more and more extensively in medical science, the iron and steel industry, geological prospecting, water conservancy and the electric power, coal and chemical industries. The use of radioactive isotopes in agriculture is also being studied.

A national industrial and communications exhibition, which opened in Peiping in September, shed some new and interesting light on China's advances in nuclear research. On display, apart from models of the country's first experimental atomic reactor, cyclotron and electrostatic generator, are more than 200 other items, including Chinese-made laboratory facilities, charts and uranium ore specimens.

China, according to a recent Peiping radio broadcast, is "rich in uranium ore reserves." Specimens of different uranium ores and samples of uranium compounds and uranium metal are on show at the Peiping exhibition but the Chinese have so far given no indication of either the location or the size of their uranium reserves. There are believed to be important deposits in Sinkiang, the remote mineral-rich northwestern province where until several years ago the Russians and Chinese jointly operated petroleum and non-ferrous metals concerns. These undertakings have reverted to Chinese ownership.

Prospecting for uranium is being carried out on a considerable scale in China and in many areas peasants take part in the search for deposits, in answer to government appeals for the maximum effort to locate resources of all kinds. China is making universal, gamma-beta, pocket-size radiometers [detection instruments] and a light model radiometer for drill hole logging (NU, Dec. '58, 58). Especially in remote areas, a good deal of simple improvised equipment is used to prepare the ores.

There are models of a 5-Mev betatron and a 1-Mw (th) experimental swimming pool water reactor at the exhibition. These installations, according to a Chinese spokesman, "can be widely popularized." Over a hundred Chinese-made items of laboratory equipment include electronic instruments, trochotrons [electron beam-switching tubes] counter tubes and nuclear emulsion plates. Among these is also a Chinese-made hundred-channel pulse-height analyzer which can analyze up to 50,000 pulses per second. A magnetic beam switching tube designed by Chinese scientists is a new type of trochotron which can be used in remote control automation and telecommunications systems and electronic computers. Other interesting items in the display include a cloud chamber, a millimicrosecond oscilloscope, a gamma-ray therapy apparatus for treating tumors, and a cobalt-60 flaw seeker.

In the middle of this year Chinese scientists succeeded for the first time in separating eleven spectroscopically pure rare earths from Chinese minerals. These rare earth elements are lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, ytterbium, yttrium, holmium and erbium. Their quality is said to equal that of the British and U. S. products. The oxide of erbium separated through the Chinese process is reportedly purer than the Johnson and Smith products. Two other rare earth elements separated by the Chinese—thulium and lutecium—have a purity as high as 99% and over 90% respectively. More recently scientists working in Changchun, northeast China, have succeeded in separating europium, terbium and gadolinium. With the richest rare earth elements deposits in the world, the Chinese have hailed these successes as important steps forward.

The new Chinese University of Science and Technology opened in September in the western suburbs of Peiping is intended to speed up nuclear advances in China. Under the joint control of the Chinese Academy of Sciences and the Ministry of Education, the university is to train research workers in the most advanced branches of science. Sixteen hundred students have been enrolled and teaching staff comes mainly from top-level research workers of the Academy of Sciences.

In 1956 the Chinese mapped out a 12-year program for scientific development. But according to Kuo Mo-jo, president of the Chinese Academy of Sciences, the program will be accomplished "in much less time, in eight or perhaps even in only five years' time." And Nieh Jung-chen, a vice-premier and head of the Planning Committee for the Development of Science, has outlined the way ahead for China's scientists: "We must pay more attention to stepping up research in the newest branches of modern science and technology. We should and can master, in not too long a time, the latest techniques in atomic fission, thermo-nuclear reaction, the use of atomic energy in all fields, radio and electronics, jet propulsion, rockets and the conquest of space."

Thailand, South Korea Buy Reactors

The order for Thailand's first reactor, a 1-Mw pool, has gone to Curtiss-Wright Corp. To be completed in two years, it will be installed at Chulalongkorn Univ. in Bangkok (NU, July '58, 26) . . . The Republic of Korea has bought a General Atomic Triga 100 kw research reactor to be installed in Seoul and completed in December.

Davison Only U. S. Bidder on Agency Fuel for Japan

For the first time, the International Atomic Energy Agency opened bids last month on supplying nuclear fuel to fill a request to IAEA from Japan. The only U. S. bidder was Davison Chemical Co., which offered three tons of natural uranium at $54.34 per kg ingot metal. Société Générale de Minerais of Brussels also bid, at 1,700 Belg. frs. ($34), while the Canadian government offered uranium free of charge to IAEA, intending resale at approximately the current world price. The Agency's Board of Governors will make an award this month.

Last Calder Reactor Critical

The fourth and last unit at Britain's Calder Hall station went critical last month. The 46-Mw(e) gross unit will be tested for the next two-three months while working up to full power. Then Calder will put out 140 Mw(e) net.

Nuclear Power for Italy's Trains?

The possibility of building a pilot, 10-Mw(e) nuclear power plant for the Italian State Railways, probably near Rome, is being studied. It would serve primarily for training. The highly-electrified Italian railway system now uses over 2-million Mwh/yr, expects to use 3-million by 1960. A number of British and U. S. firms have been asked to supply data on their small reactors.

Domestic Developments in a Busy Month

AEC BUDGET: Sharp Cutbacks Reported

AEC's civilian atomic energy program for fiscal 1960 took the worst beating ever at the hands of the Budget Bureau before it was finally cleared for submission to Congress this month, according to Washington sources.

Budget Bureau pressure, which has mounted steadily in the last two years, reached a peak this year because of the huge deficit now being incurred by the federal government (upwards of $12-billion for the current fiscal year, at least half that for fiscal 1960).

Two proposed AEC budgets for '60, starting July 1, were rejected by the Budget Bureau before a final version was worked out late in December. Both military and civilian activities of AEC were affected, but the latter were cut more sharply.

Meanwhile, AEC officials told NUCLEONICS that they have completed a 2% reduction-in-force ordered by the Budget Bureau early last fall. Total AEC employment prior to the order was just under 7,000; as of December 15, it was down to just over 6,800.

Arthur Tackman, director of organization and personnel, said the cut came through normal attrition and that no one had been fired. In the merger of the reactor development and industrial development divisions (NU, Nov. '58, 22), he said, there were some personnel shifts involving only a handful of people. He said the new reactor development division was not up to authorized strength of 193 and could take on several people, adding: "This certainly has had no significant affect on the Division of Reactor Development."

INVESTIGATION: AEC Procedures Probed

AEC's organization and its budgeting and contracting procedures have been under investigation by the Joint Committee on Atomic Energy since August, two JCAE members revealed last month. The inquiry has been disclosed to new AEC Chairman John A. McCone on Aug. 19 in a letter from Reps. Melvin Price (D–Ill.) and Chet Holifield (D–Calif.), chairmen respectively of JCAE subcommittees on research and development and on legislation. Price and Holifield made public their letter, and a reply by Acting General Manager Paul Foster offering "all possible" AEC assistance.

Although it's billed as a friendly inquiry, one result will be heightened pressure against any holdback of funds for projects voted by Congress. Areas to be covered by the probe include:

Budgeting: JCAE wants to know the effects of Budget Bureau fund holdbacks on contractors and scientists, and the extent to which AEC scientists and engineers must spend time on budgetary matters.

Contracting: Having noted apparent bottlenecks in getting contracts negotiated, approved in Washington and executed, JCAE wants to know whether contract negotiation has been overly centralized in Washington and whether AEC's Controller exercises veto power.

Organization: Are the policy and decision-making levels of AEC getting bogged down in details, and are higher salaries in Washington causing an excessive drift of able field men to headquarters.

Given as major reasons for the study were AEC "delays in submitting important recommendations for legislative action, delays in contract negotiations, and delays in taking action on matters requested by JCAE and the Congress."

The probers are particularly interested in progress of certain projects: the proposed plutonium-production reactor, the gas-cooled reactor, design studies authorized by JCAE on more advanced reactors, the over-all reactor demonstration program, and certain physical research facilities. Target date for a report on the inquiry is March 1.

McCone has made it clear he will go out of his way to keep peace with the Democratic-controlled JCAE. He has already moved—by coincidence or otherwise—to satisfy it on some points. He has indicated AEC will build the new Hanford Pu reactor, despite past White House objections, and also the gas-cooled reactor if industry proves unwilling to build an acceptable plant under the demonstration program.

JCAE sources stress that AEC is cooperating fully with Committee staff investigators. The inquiry thus far has taken the form of conferences at which the latter discuss possible avenues of improvement with AEC representatives. "It's not a case of the Committee trying to get some ammunition which we'll spring on them at some later date," explains one source.

The holdback-of-funds issue may be linked with lagging development of the nuclear airplane, also long a sore point with JCAE. Some Committee Democrats are determined the program should go full speed ahead, but there's doubt the Administration is willing to ask, or spend, the money. It's speculated that ANP, rather than atomic power, may be the center of controversy this year.

PRDC CASE: AEC Rules for Company

AEC has tentatively confirmed its 1956 decision licensing the Power Reactor Development Co. to construct a fast-breeder power reactor at Lagoona Beach, Mich., but the company gets no real assurance that Commission approval won't be withdrawn later.

Commissioners Vance and Floberg joined in the opinion and initial decision. Graham concurs in a separate opinion. Libby didn't take part because of illness. McCone abstained because he wasn't with AEC when the arguments were held.

The decision is an intermediate one: parties have 20 days to file exceptions. If none are received, the order is final; otherwise AEC will formally issue a final decision after consideration of the exceptions.

Like all construction permits, this one is provisional in that an operating license will not be issued until the complete, final hazards summary report is submitted to AEC. This permit, however, is further provisional to the extent that AEC reserves jurisdiction, at any time prior to issuance of an operating license, to reopen the proceeding for receipt of additional evidence, and to take such action on continuance, modification or cancellation of the construction permit as the record warrants.

Once AEC is finally assured the plant can and will be operated safely, the operating license will be issued.

But the decision notes that "the Commission regards the importance of public safety so highly that it considers that it does not lose jurisdiction of this subject even after a

license has been issued, at any stage in the course of construction, or for that matter, even after a facility is in operation."

Among the findings in the 49-page decision:

" . . . there is no inherent hazard or danger to the health and safety of the public in the construction or operation of fast breeder reactors . . . in view of the population density around the site, its suitability for the proposed reactor depends upon the inherent safety of the reactor and a demonstration that no credible accident can release significant quantities of fission products into the atmosphere. If the foregoing are established, and there is reasonable assurance that they can be, it is probable that the site will prove suitable for the proposed reactor.

" . . . the record indicates that none of the questions relating to reactor safety, the feasibility of the reactor design and the adequacy of the financing can be absoluted and finally answered at this time."

PRDC must file quarterly safety, and semiannual financial reports, to be made public.

Not surprisingly, the PRDC reaction to AEC's action was favorable, that of the intervening unions unfavorable. Benjamin Sigal, union attorney, said the group would file exceptions, adding: "We feel that the Commission failed to meet our objections on a number of points."

SEAWOLF: Sodium Reactor Retired

After driving *Seawolf* 71,609 nautical miles, the S2G sodium-cooled reactor was scrammed for the last time on Dec. 13. *Seawolf* will be out of commission for about a year while S2G is removed and a Westinghouse water plant installed (NU, March '58, 25).

HTRE-3: Suffers an Excursion

The High Temperature Reactor Experiment–3, a unit in GE's nuclear airplane program at the Idaho testing station, went briefly out of control Nov. 18 and damaged its core. Due to "a minor control failure," the "small excursion" caused a small release of radioactivity but no hazard to personnel, AEC said. HTRE-3 is being disassembled remotely in the hot shop at the test station. Officials refused comment on extent of damage or time required for repairs.

EURATOM: Fuel Rules Well Received

AEC officials said they have had a generally good reception to proposed fuel-guaranty criteria for U. S. manufacturers under the Euratom program (NU, Oct. '58, 24). Fuel suppliers were called in one by one, then together on Dec. 18, to discuss criteria designed to limit AEC subsidy on fuel to $90-million over 10 years.

Based on industry comments, AEC said the criteria would be revised in time for submission to Congress when the U. S.-Euratom bilateral is reviewed later this month. Basically, the proposed criteria relate the total support money available to the 1-million-kw goal of the program. If a supplier is furnishing fuel for a 100-Mw(e) reactor under the program, for example, he must guarantee fuel burnup and price ceiling which, combined, would not run AEC's subsidy over $9-million.

AEC has guaranteed burnup of 10,000 Mwd/ton for the Euratom reactors at prices not to exceed $100/kg for stainless-steel fuel elements and $140/kg for zirconium-clad elements. Thus, AEC would make up the difference between these and private guarantees.

Meanwhile, AEC officials also reported that the U. S. and Euratom staffs have reached agreement on the ground rules for the overall program (NU, Dec. '58, 23).

TASK FORCE: New Liquid-Fuel Review

A 15-man task force met in Washington in mid-December to begin a 10-week review of three liquid-fuel concepts in the U. S. reactor program: liquid-metal-fueled, aqueous-homogeneous and fused-salt. The force is expected to report by early March on the relative merits, status, and required-development for all three systems. The study will be a comparative analysis of the three systems and of them as against other concepts.

It was scheduled after AEC was unable to get all the money it requested from the Budget Bureau to support these systems during the fiscal year beginning July 1 (fiscal 1960). AEC went to its new ad hoc committee on reactor policies (NU, Nov. '58, 25) for advice on the systems but the committee suggested a task-force study.

Members of the force include: Robert Ritzman, chairman, and Robert Blum, vice-chairman, both of AEC's evaluation branch, Division of Reactor Development; Joseph Draley and Robert Avery, Argonne National Laboratory; Frank Miles and John Chernick, Brookhaven; H. G. McPherson and R. B. Briggs, Oak Ridge; Vincent Walker, Phillips Petroleum; E. E. Hayes and J. E. Evans, Dupont (Savannah River); Titus LeClair, Edison Electric Institute (vice president, Commonwealth Edison); R. H. Shannon, United Engineers; Jack B. McKarney, Ebasco Services; Wilson R. Cooper, TVA; and Jack S. Bitel (alternate to LeClair). Consultants are David H. Fax, Westinghouse, and Robert T. Schomer, Babcock & Wilcox.

PIQUA: ACRS Reviews New Site

The beleaguered Piqua reactor took on a more hopeful outlook last month as the Advisory Committee on Reactor Safeguards met to review the project's new site and changes in reactor design (NU, Dec. '58, 25). A new ACRS report was expected to be submitted to AEC before the end of December.

The original site was found unsuitable by ACRS (NU, Oct. '58, 27) more than two years after the project had been proposed. AEC officials said the Piqua experience would result in early site investigations on future reactor projects.

TEST REACTORS: AEC to Get 3 or 4 Bids

Industrial Testing Reactors, Inc., of Charlotte, N. C., disclosed last month that General Electric has been redesigning ITR's proposed test reactor to meet new AEC requirements under the Commission's program to lease test-reactor space on five-year contracts (NU, May '58, 26; Nov., 23). ITR officials said they would make a space-rental proposal to AEC by the Jan. 12 deadline, joining Westinghouse (WTR) and GE (GETR) in doing so. A fourth, it is understood, may come from ACF–Kaiser–Lockheed–Phillips Petroleum (Sept. '57, 30).

AEC's new requirements were outlined to industry officials at a closed meeting in late November. AEC officials announced they had increased the requirements from those published in October but that the 50% ceiling on program business for any one firm had been cut to "about 30%." Total AEC obligational authority for space rental is

$15-million for five years; the space would be used to meet the needs of the fuel-cycle development program, AEC projects that cannot be accommodated by AEC's Materials or Engineering Test Reactors, and civilian projects supported with AEC funds.

The changes caught some industry people by surprise. AEC officials explained that "at least three reactors are needed" to meet its foreseeable requirements and that these were such they could not be met by WTR and GETR alone. "While we can use some space in the GE and Westinghouse reactors," an official said, "there are some limitations in these facilities."

An ITR official said construction of this new firm's reactor had purposely been delayed, pending development of the test program requirements; it was originally scheduled for a construction start by July 1 (NU, May '58, 26). He said ITR's redesigned reactor would not only be larger than those of GE and Westinghouse but would meet the increased flux requirements of AEC.

"Our fluxes will be considerably higher than WTR with the design changes," he declared.

Coordination of space assignment under the program is being handled by Ira Zartmann of AEC's Reactor Development division.

REACTORS: AEC Assigns 6 Studies

Six reactor study assignments—three for advancing relatively well-developed types and three for investigating radical new concepts—were awarded by AEC last month.

Winners in the hot competition on pushing further the familiar types (32 architect-engineering firms offered 86 proposals in response to AEC's September invitation) were:

Pressurized water: Stone & Webster, with Combustion Engineering;

Boiling water: Ebasco, with General Electric;

Organic moderated: Bechtel, with Atomics International.

These studies are to determine the design that would lead to the most economic power station using each concept; the possibility of starting to build a unit of that design by July 1960 will be one object of the studies. However AEC has not committed itself to build any of the reactors. Reports on the first phase of work are due by March 23 at AEC, which in turn is required to report to the Joint Committee on Atomic Energy by May 1.

One earlier study award was made on heavy water reactors to Sargent & Lundy with Nuclear Development Corp. of America.

The other three studies—each estimated to cost $150,000—are to be carried out by American Radiator & Standard Sanitary Corp., on a mercury-cooled fast breeder; GE on a modified sodium–graphite unit with modules containing fuel and coolant; and Babcock & Wilcox on a gas-suspension-coolant reactor. These proposals were among 20 filed with AEC under a new program in which AEC will evaluate unsolicited proposals from industry on new concepts of reactors for power, heat, or other industrial uses. Proposals may be submitted any time; those received by Aug. 31 and Feb. 28 will be reviewed in September and March each year.

MERGERS: Four Firms Negotiating

"Merger" was the word of the month in December as four firms in the industry reached the serious-negotiation stage. Talking acquisition were: Combustion Engineering, to acquire General Nuclear Engineering Corp.; and Texas Instruments, to acquire Metals & Controls.

CE sources said they had expected negotiations to be completed late in November, but that there had been minor delays of a legal nature. A merger of GNEC, headed by Walter Zinn, and Combustion would give the latter its highest stature yet in the reactor-manufacturing industry. The company is in the naval reactor program but as yet has no civilian reactor projects. GNEC has been working on reactor designs for the Florida and Carolina-Virginia groups, Puerto Rico and Cuba.

M & C's subsidiary M & C Nuclear has a large fuel-element fabricating plant, most of its production going to naval reactors.

N. Y. STATE: Public Nuclear Power?

The New York State Power Authority, led by tempestuous Robert Moses, has exploded a peaceful nuclear bomb on the eve of Governor-elect Nelson Rockefeller's inauguration. The Authority has asked for sole jurisdiction over nuclear power in the State, including permission to build a 400–500-Mw(e) nuclear power plant upstate, provided federal construction subsidies can be obtained.

The Authority's request appears to have been timed to exploit possible changes this year in both State and federal nuclear policies. The State legislature is again expected to consider an act setting policy on the atom and assigning jurisdiction to State agencies; in Washington, the Joint Committee on Atomic Energy will press for expanded federal support of reactor construction by both public and private power.

Maj. Gen. Thomas F. Farrell, who wrote the Power Authority's report, told NUCLEONICS that the Authority wants to take advantage of capital subsidies if Congress should authorize them. He noted that his report also suggests construction of a coal-fired power station upstate but said the Authority would prefer a nuclear station if the federal government would absorb the difference in construction costs. He insisted that the project should not be considered a public-vs-private power issue because its electricity would be sold wholesale to private and public retailers.

FUEL CYCLE: AEC Work in Demand

AEC last month received a whopping 107 proposals—from 39 firms—under its program to reduce the costs of nuclear fuel ("fuel-cycle development program," NU, Nov. '58, 23). About $13.5-million is available to support development contracts at all points on the fuel cycle.

Meanwhile, AEC said eight firms had filed development proposals under the special oxide-fuel program. The proposals cover performance of research-development on oxide fuels and for the design of a fast breeder reactor using a plutonium oxide-uranium oxide cycle.

PMP-1: 9 Bid on New Reactor

AEC's factory-assembled modular reactor—a pressurized water unit whose modules can be airlifted to remote sites and rapidly connected—will be built at Sundance Air Force Station in Wyoming. Called PMP-1 for Portable Medium Power reactor No. 1, it will use enriched U fuel, produce 1 Mw power and 2 Mw space heat. Proposing to build it are Alco, Associated Nucleonics, Combustion Engineering, Curtiss-Wright, H. K. Ferguson, Lockheed, Martin, Westinghouse and Shiflet Bros. of Abilene, Tex. Construction is to take 30 months.

Spevack Case Challenges AEC Dissemination Rights

On April 10, 1957, a New Rochelle, N. Y., scientist—Jerome S. Spevack—went into the Federal District Court for the District of Columbia and successfully appealed for a restraining order against AEC publication of his improved process for the production of heavy water. In the 21 months during which the order has been in effect, Spevack, AEC, the Department of Justice and two "friends of the court"—the American Chemical Society and the Engineers Joint Council—have been in and out of federal court four times.

Last month, they found themselves in court for the fifth and, probably, last time as the U. S. Supreme Court agreed to review a Court-of-Appeals decision against Spevack. Presented as major issues by the parties are these questions:

Spevack: Can AEC—by general publication—dispose of property which it allegedly does not own—specifically, a process on which Spevack has applied for a patent? If so, is the 1954 Atomic Energy Act, under which AEC operates, unconstitutional in permitting the taking of private property without due process of law or just compensation?

AEC and Justice Dept.: Did Spevack forfeit his property rights when he disclosed the key improvements in his process to AEC while under contract as a consultant in 1949? Even if he did not, should AEC be stopped from its responsibility under the 1954 Act to disseminate information "essential to scientific and industrial progress"?

ACS and EJC: Would a decision in favor of the government and against Spevack adversely affect the patent rights of thousands of the nation's scientists and engineers, including their right to file abroad within a year after making patent application in the U. S.?

Dat 'Ole Debbil, Secrecy

Spevack v. Strauss, et al., as the Spevack case is known in the courts, has had two distinguishing characteristics: 1. it is the first to test the information-dissemination provisions of the 1954 Act; and 2. it has been conducted in almost total secrecy, by court order. During the legal gyrations from District Court to Court of Appeals to Supreme Court, back to Court of Appeals and back, now, to Supreme Court, no details of the allegedly improved process have been revealed. The government, however, has outlined the history of the case, as it sees it, in its latest brief to the Supreme Court:

Spevack, the government says, invented a dual-temperature exchange process for D_2O production while employed by a Manhattan District contractor during 1943. His application for a patent between 1943 and 1946 was put under a secrecy order because all D_2O technology was then classified. The patent, finally issued to him on April 2, 1957, was assigned to AEC.

Between 1946 and 1949, while self-employed, Spevack developed "what he considers a new and improved process," the government reports. In October, 1949, Spevack was hired under contract as an AEC consultant; in this capacity, he filed a report outlining the allegedly improved process but reserving any invention rights.

A patent application describing the alleged improvements was filed by Spevack on Sept. 29, 1950. Because everything on D_2O production continued classified, a secrecy order was applied to the new application. While the secrecy order remained in effect, Spevack could not file abroad under the international convention giving him one year after application in the U. S.

Late in 1956, according to the government, AEC decided to declassify all D_2O-production information. In January, 1957, Spevack allegedly requested declassification of his reports in sufficient time to permit him to describe his processes at a Dutch conference scheduled for April. In the meantime, AEC had begun publication of D_2O reports and had "opened its plants to the public"; the secrecy orders against Spevack's inventions were rescinded on February 1, 1957.

At this juncture, the government alleged, Spevack "apparently changed his mind" about publication and asked for a delay so he could file in several foreign countries. On March 21, AEC agreed to postpone publication for thirty days—or until "the time of the opening of the Amsterdam conference at which Mr. Spevack had planned to describe the entire processes," the government said. On April 10, Spevack filed his complaint for injunctive relief against AEC.

Patent Probe

The Joint Committee on Atomic Energy has scheduled nuclear patent hearings in April. Of primary concern will be the compulsory licensing provisions of the 1954 Act, which expire Aug. 31, 1959, unless renewed; but the hearings will cover the entire patent picture.

Question Mooted?

Spevack's principal complaint is this: had a secrecy order not been imposed on his 1950 patent application, he would have had a year to file for foreign patents. The government insists: first, the whole question of giving Spevack protection has been mooted by AEC publication of D_2O information before his restraining order was granted; and, second, he has already had more than a year as a result of his suit.

By April 16 of this year, according to the government, Spevack had filed in 12 countries and was applying in a thirteenth; he has had several months since then in which to meet his over-all goal of 21 foreign filings, the government added.

The government also makes the broader argument—on which it won in the Court of Appeals—that "there are certain situations in which [AEC is] clearly authorized to publish invention rights not owned by the U. S. . . ." Section 141(b) of the 1954 Act, the government argues, not only permits but "indeed, requires" the publication of unclassified information on atomic energy.

Spevack's information, the government asserts, "is inseparable from that great mass of public information" on D_2O which belongs to the U. S. and which has already been published. The inventor's only course, if he has been injured by such publication, the government contends, is to seek just compensation in the Court of Claims.

ACS, EJC Views

ACS and EJC have intervened because of the broader issue—AEC's right to publish inventions which it does not own. ACS accuses AEC of publishing details of an invention "revealed to it in confidence," by law, "without regard to rights of inventors in the respect of their patent applications." ACS adds: "The importance of this question to the American Chemical Society cannot be overstated." EJC told the Supreme Court:

"If our nation's inventors have no way of protecting their property rights, which is the necessary result of the decision of the lower court [Appeals], the initiative of engineers and scientists will be curtailed at a time when our country is in dire need of scientific knowledge."

Reactor News

Combustion to Operate ALPR

The Argonne Low Power Reactor, dedicated in Idaho last month, will be operated by Combustion Engineering; AEC is negotiating with the firm's nuclear division, its choice from among 13 bidders. Designed for the military to provide power for small outposts in remote, difficult locations, it has an output of 3 Mw(th), and produces 200 kw electricity and 400 kw space heat (NU, Sept. '58, 154).

AEC's New U Policy Seen Blessing in Disguise

Repudiating its earlier attack on AEC's new uranium-purchase policy (NU, Dec. '58, 27), the Uranium Institute of America has publicly welcomed the action as a "blessing in disguise." Major benefits of the move, according to UIA: a binding AEC commitment to purchase $300-million annually of U concentrates through March, 1966. UIA said AEC had had no legal obligation to buy at its $8/lb minimum price beyond 1962, except where some contracts had been extended to 1966.

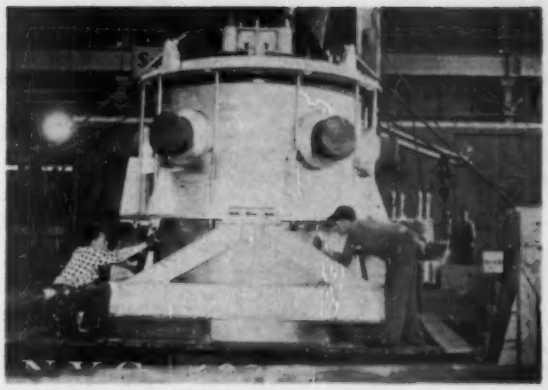
Los Alamos Studying Explosive Propulsion

Los Alamos Scientific Laboratory is studying the propulsion of rockets by a series of small nuclear explosions, a concept originally proposed by the lab's Stanislaw Ulam, according to LASL; ideas and progress reports will be exchanged with **General Atomic**, working independently for the Air Force (NU, Aug. '58, 25).

NDA Unveils Low-Power Reactor

PRR—the Pawling Research Reactor, Nuclear Development Corp. of America's entry in the small-reactor field, has gone into operation at NDA's Pawling Laboratories. Prototype of a Teaching and Research Reactor (TRR) for university use, PRR is heavy-water moderated and cooled, and operates at 5 watts normal, 100 watts maximum. The core consists of 40 plates of U-Al containing one kg fully-enriched U; the reactor tank is considerably larger (5 ft dia, 4 ft high) than the fuel assembly in its center, affording a large unencumbered space for experiments. Surrounding the sides and bottom of the tank is a 1-ft layer of graphite, enclosed by several inches of hydrogenous Masonite—equivalent of several inches of water in reflecting capacity. PRR has no self-contained shielding but is placed in a fully-shielded room: during shutdown, it is fully accessible.

KIWI-A, first experimental nuclear rocket reactor (NU, July '58, 25) will soon go critical at Jackass Flats, Nev., testing grounds. Operating temperature will exceed 3,000° F but coolant-duct size implies average power density much lower than the 50 Mw/ft³ or more needed for flight



SKIPJACK REACTOR VESSEL shown, in rare photo just cleared for NUCLEONICS, as it was shipped from Barberton, Ohio, plant of Babcock & Wilcox. Bottom half of vessel is hidden inside railroad gondola car (for scale, note New York Central markings bottom left). Reactor is third-generation pressurized-water submarine engine

Borax 5 to Work on Nuclear Superheat

AEC is planning to modify and rebuild the 20-Mw(th) Borax-4 into a 40-Mw Borax-5 aimed primarily at testing fuel samples and other materials for nuclear superheaters. The work is to be done by year's end.

AEC Would Make Safety Records Public

AEC has served notice that it is ready to open its existing and future files on radiation accident reports and on correspondence with licensees concerning results of AEC facility inspections. The public was given until Dec. 27 to comment on the proposed rule. An AEC official said the proposal was a step in putting AEC's licensing operations on a public basis. Reports and correspondence would go into public files at AEC's downtown Washington, D. C., office.

Access Clearances to Cost

Effective Dec. 31, AEC is charging $385 for each "Q" and $15 for each "L" clearance under its access permit program; clearances had been free.

Fluor Designing Reactor to De-salt Water

Interior Dept. officials said last month that Fluor Corp. is engineering a low-temperature, low-pressure, boiling-water reactor for possible construction under the government's program to build five pilot plants for freshening salt or brackish water (NU, Oct. '57, 29). Fluor is designing the plant under a $100,000 contract sponsored by Interior ($60,000) and the State of California ($40,000). The company estimates it could distill sea water with nuclear heat for about $0.50/gal; Interior officials said this compares with $2–3/gal in existing plants.

Industry Asked to Back Hi-Level Irradiator

AEC has invited private industry to sponsor—with Commission help—the first irradiator to be built for general research and development work on industrial applications of high-level radiation. AEC said it would provide up to 1-million curies of cobalt-60, without charge, and will consider other forms of assistance if private interests would take on the project. If not, AEC is prepared to build the facility at a government-owned installation at a cost of $1.6-million, exclusive of radiation source. Industry proposals were due Dec. 31.

PAR: Big Homogeneous Dropped

Pennsylvania Power & Light Co. and Westinghouse have dropped their project to build a 70–150-Mw(e) homogeneous U-Th slurry reactor.

This elusive will-o'-the-wisp of "a pot, a pipe and a pump" that the homogeneous system has been holding out eludes the second and last industrial attempt to harness this attractively simple concept: Wolverine Electric Coop. of Michigan dropped its 10-Mw(e) aqueous homogeneous project earlier (NU, Oct. '57, 19; June '58, 25).

The decision had immediate political repercussions on another advanced project, the General Atomic high-temperature gas-cooled reactor design for PP&L's neighbor, Philadelphia Electric Co. associated with 51 other utilities (NU, Dec. '58, 17). Sen. Clinton P. Anderson (D–N. M.), incoming chairman of the Joint Committee on Atomic Energy, has long held that advanced reactor types are too expensive for private industry to develop alone: that they should be proved out by the government first, and turned over to industry when commercially exploitable. Anderson's opposition to the General Atomic project is now expected as a certainty. Earlier indications had been that AEC would approve the GA project by 4-1 vote.

The decision to drop the homogeneous PAR (Pennsylvania Advanced Reactor) resulted from a technical determination that PP&L and Westinghouse could not, as they had planned, proceed immediately to build a large-scale plant, NUCLEONICS learned, but that a small prototype was an indispensable prerequisite. The two companies felt that they could not between them afford the construction cost of such a prototype, "and so we put our problem before the AEC. They have their budget problems too."

AEC was first formally notified of the situation on Dec. 1, and the two companies decided to abandon the project on Dec. 15. However the project "will be terminated in a very logical way," with the final reference design being completed so that the research and development done will form "a complete package." Project staff will be phased out over the next two months; Westinghouse's intention is to absorb all its PAR personnel elsewhere in its Atomic Power Department.

Between them the two companies will have spent $9-million on PAR, which has been entirely financed with private money. AEC had been asked for third-round aid money and negotiations were under way (NU, Jan. '58, 26; March, 28; May, 18), but no AEC money has gone into the project.

PAR officials say they are "as convinced as ever of the need for this program" in the national effort on nuclear power. "We do not say this plant is not feasible, but only that it is not feasible without a prototype." They were pushed to this conclusion because "when you are 90% sure of this and 80% sure of that and 70% sure of the other, and all have to work together, what is the total reliability of the system?" Also there was the warning inherent in Oak Ridge's problems with the Homogeneous Reactor Experiment–2. Finally, there is the problem of increasing costs.

Total cost of the plant was to have been $107.7-million, of which AEC had been asked for $25.3-million. Originally when the project was first announced in July 1955, it was to be entirely privately financed. It was then stated that if the reactor were built, it would produce power at a cost no greater than that elsewhere on PP&L's system—the first time such a statement was made.

Anderson's Reaction

Senator Anderson commented that "this project demonstrates the fallacy of expecting private industry to provide the technical direction and financing for construction of advanced reactor concepts . . . I hope AEC and parts of industry will re-examine their views in the light of this experience. It is undesirable to permit the field of advanced atomic power concepts to be staked out as the private domain of industry . . . We may have to decide whether we should learn to walk before we run."

Anderson, who has been critical of top PP&L officials as being in the forefront of those opposing federal reactor construction, charged the project was undertaken "as a means of keeping the government from developing an advanced atomic power concept."

NOTE: The NUCLEONICS statistics have been dropped this month to make room for the late-breaking story above.

CURRIE: New B&W Vice President

Lauchlin M. Currie reported to Babcock & Wilcox Co. on Dec. 15 as vice president in charge of the atomic energy division, having retired as vice president of Union Carbide Nuclear Co.

The switch, it is understood, will bring no significant change in B & W's nuclear policy; rather, it is aimed at strengthening the company's marketing position and, within the company, will give the atomic energy division its first vice president. W. T. Moore and John Landis will continue as division manager and assistant manager.

Currie, 60, would have been compulsorily retired by Union Carbide at 65 had he elected to stay on; B & W has no compulsory retirement.

RADIATION: AEC Gets 109 Proposals

AEC officials reported last month that they have had 109 proposals for radiation development contracts since they launched, in mid-1958, their five-year program to accelerate radiation use by industry, medicine and agriculture (NU, Oct. '58, 21).

Through Dec. 15, the Office of Isotopes and Radiation Development had let 23 contracts under the program, all expiring before the end of the current fiscal year.

FLOBERG: Limits to AEC Support?

Commissioner John F. Floberg raised a lot of questions about the future of reactor development last month for which he offered few answers. It was his second speech in a month warning the industry that AEC would have to be selective in its support of concepts.

As he did in a November address to the Atomic Industrial Forum (NU, Dec. '58, 21) Floberg voiced his belief that it may now be prudent to spend a little more effort on improving present reactor technology and a little less time developing new technology. He sought industry advice on these questions: What level of effort on civilian power? How many concepts? When should we give up on a concept?

". . . from time to time," Floberg observed, "it will be necessary to reorient the program and to acknowledge that we should go no farther with certain lines of effort."

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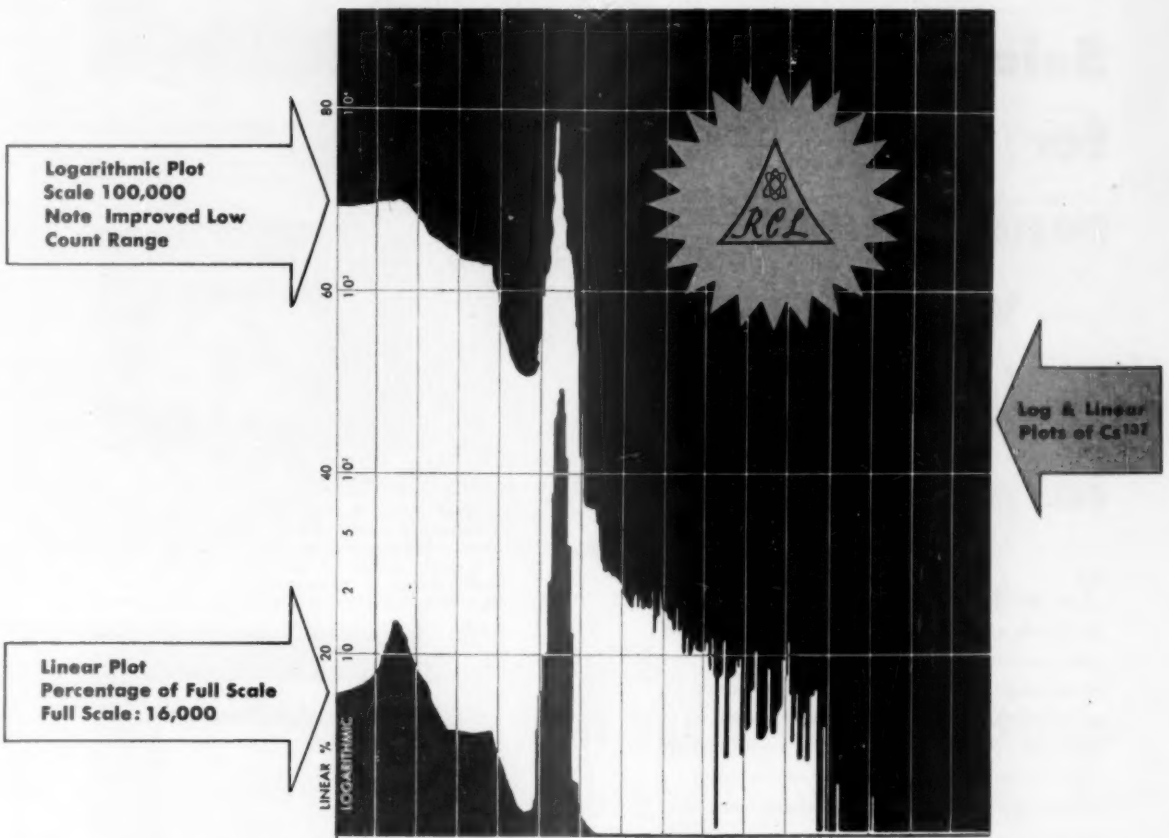

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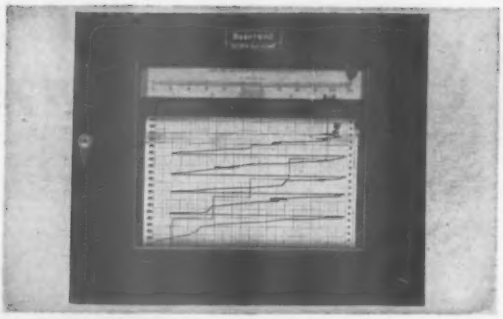

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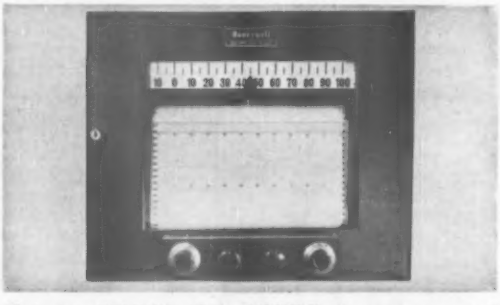

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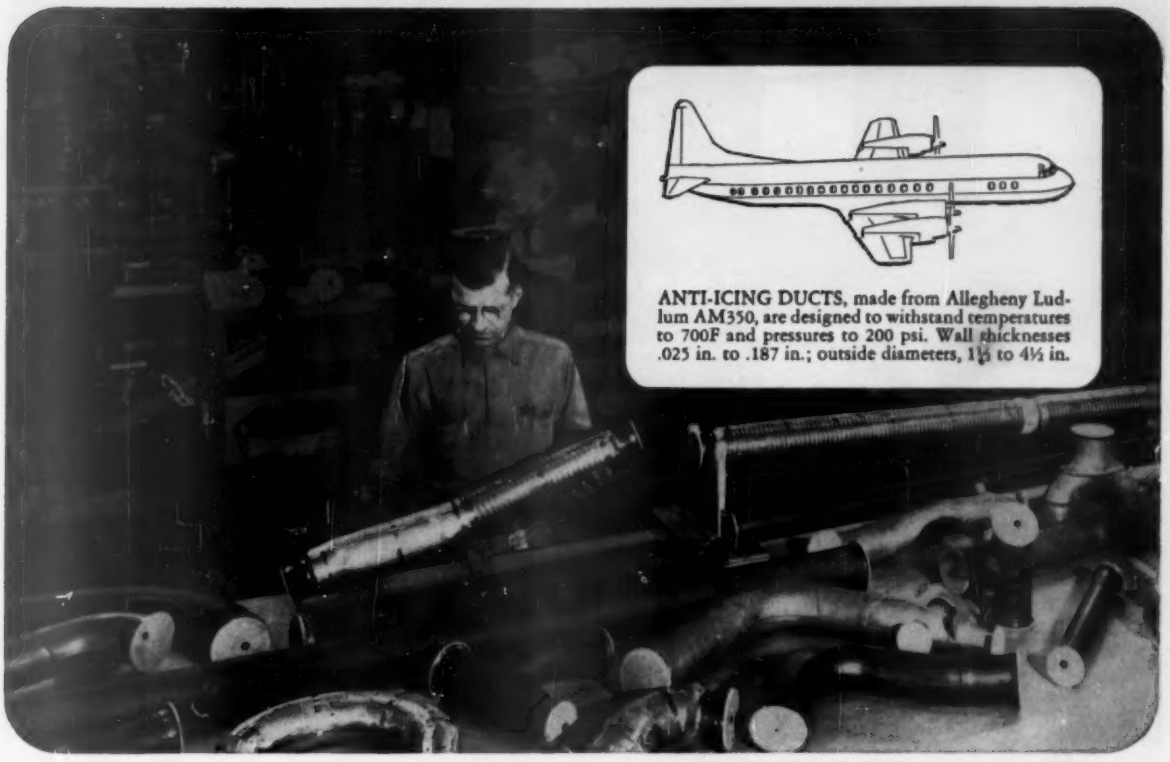

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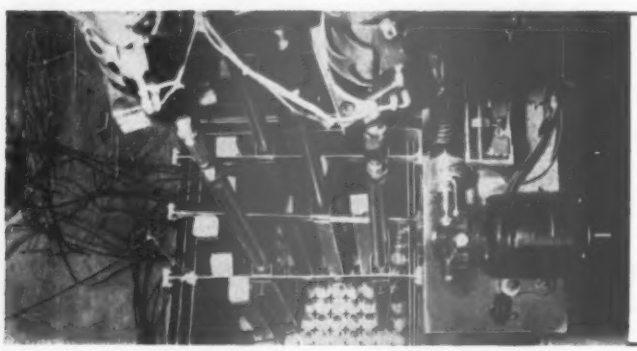

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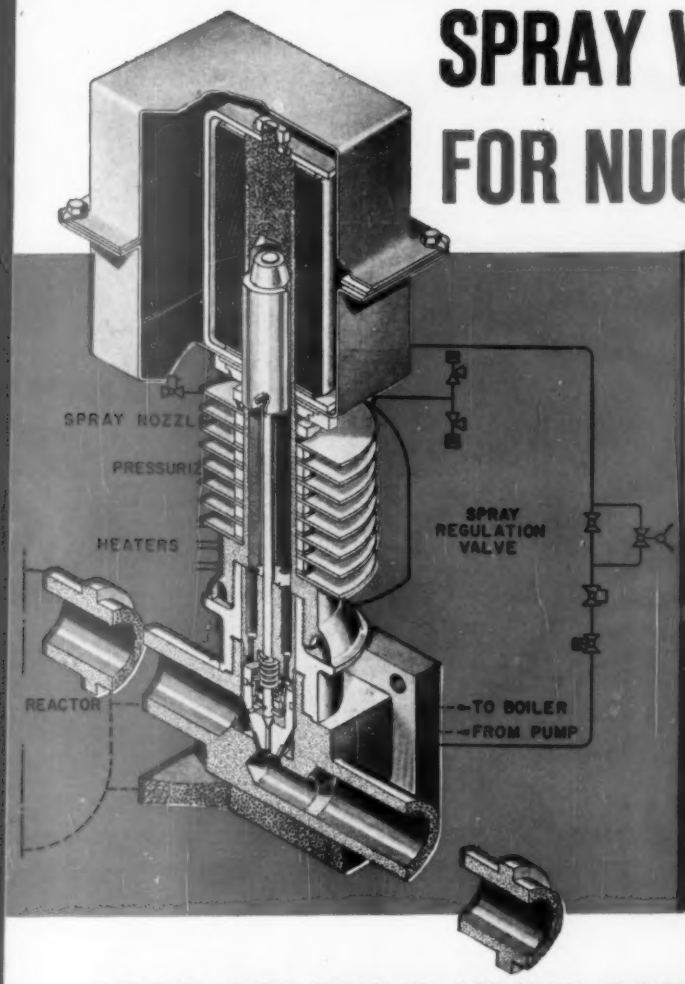

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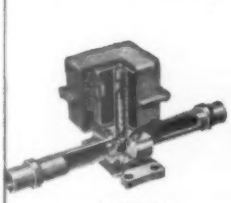
Primary System

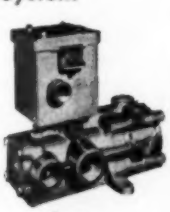


Isolating (Stop) Valve

Pressure Operated 4-way Valve

Secondary System

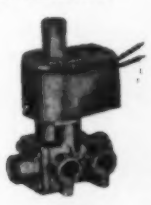
Manual Reset 2-way Valves



4-way Valves

Instrumentation Control

Manual Reset Valves



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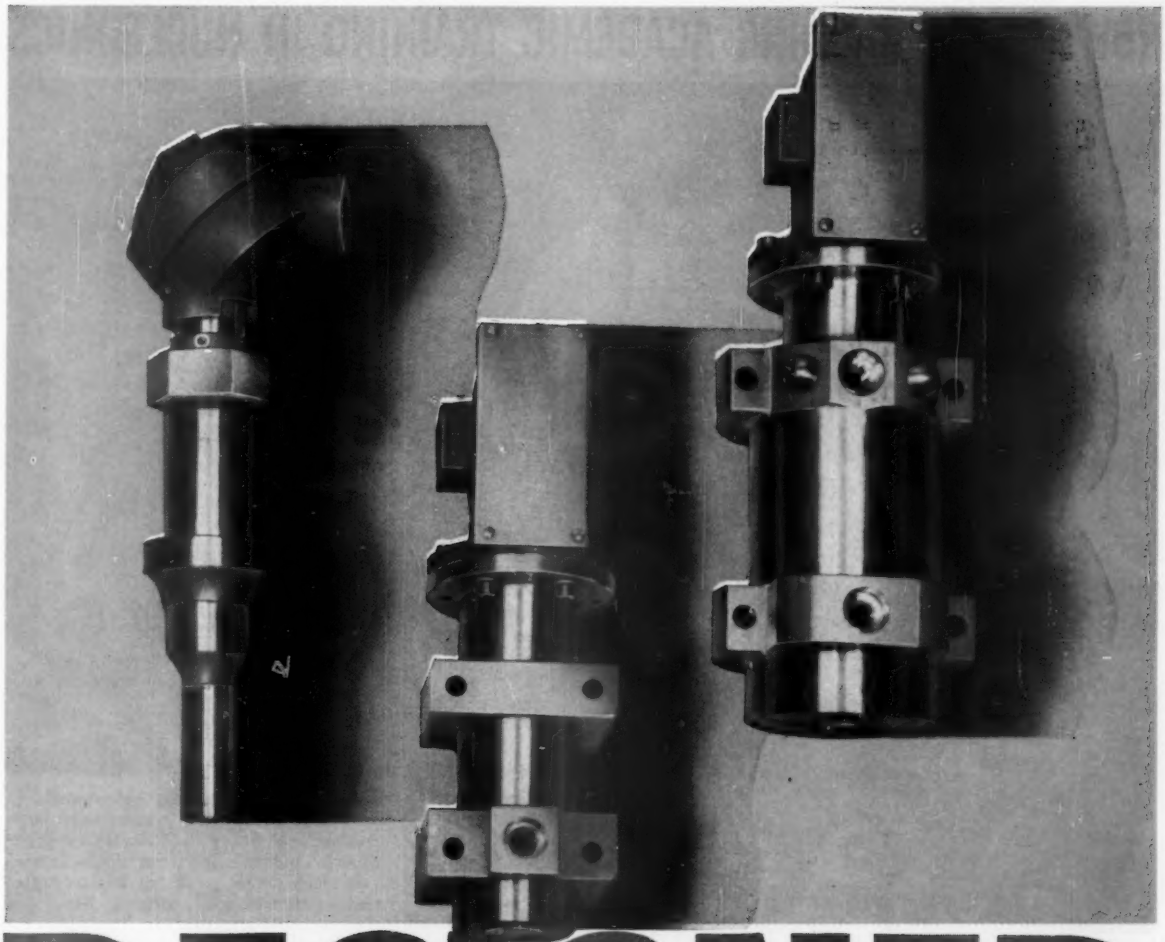

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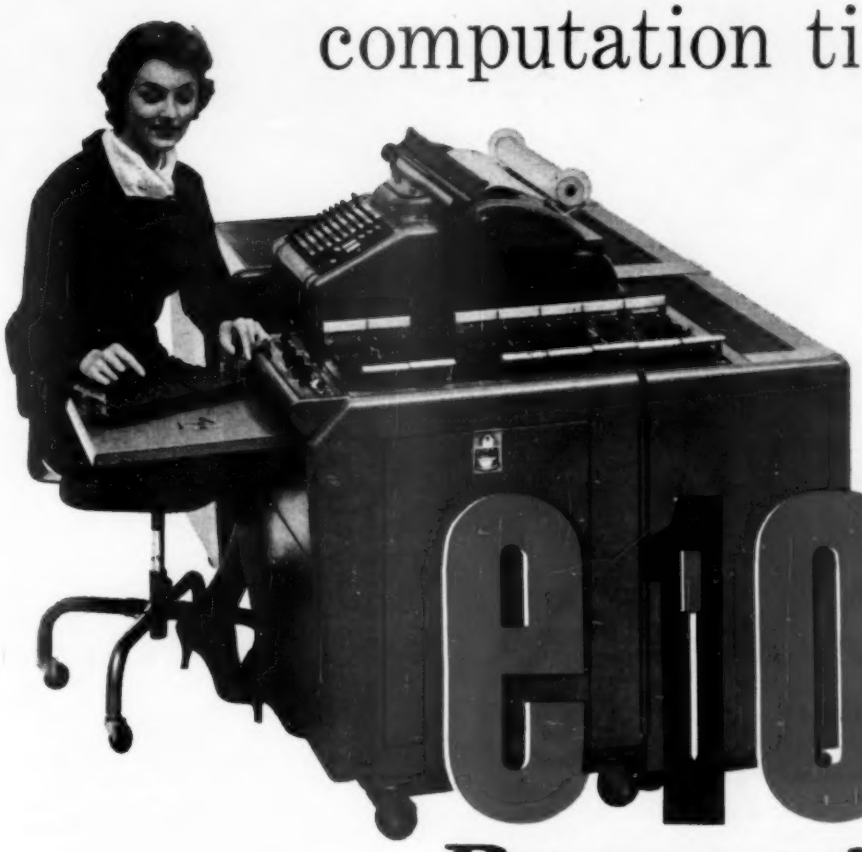

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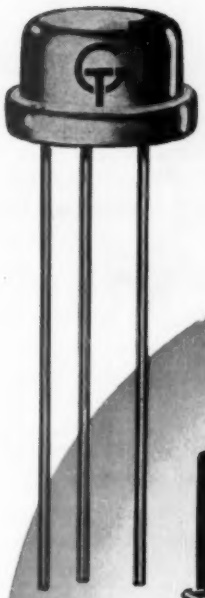

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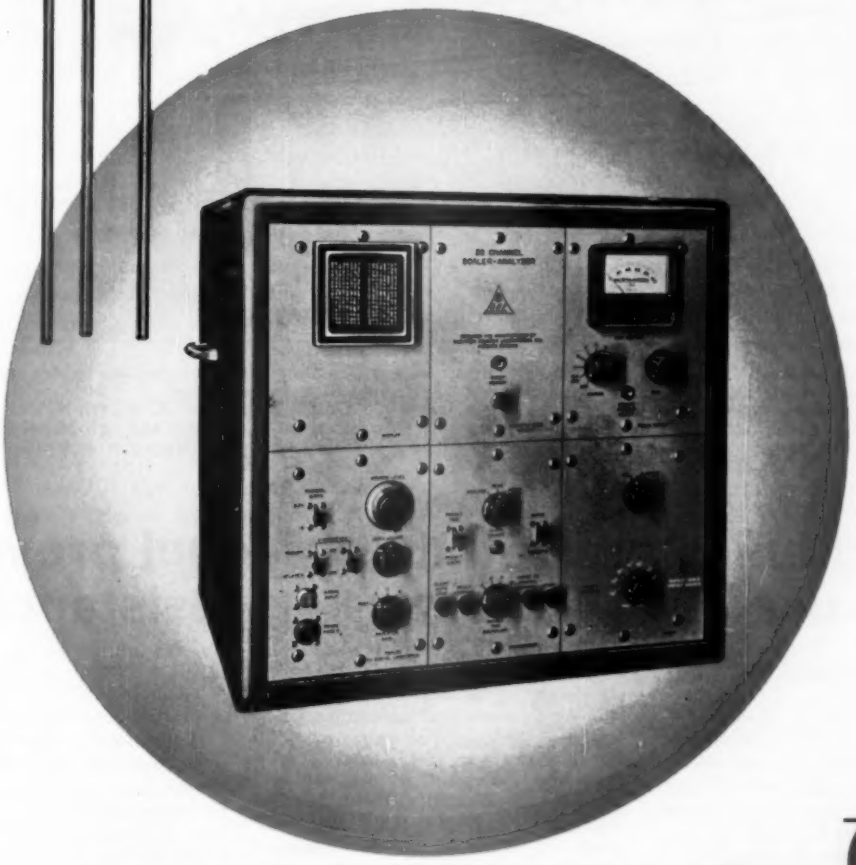

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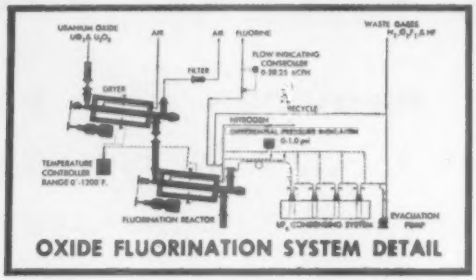

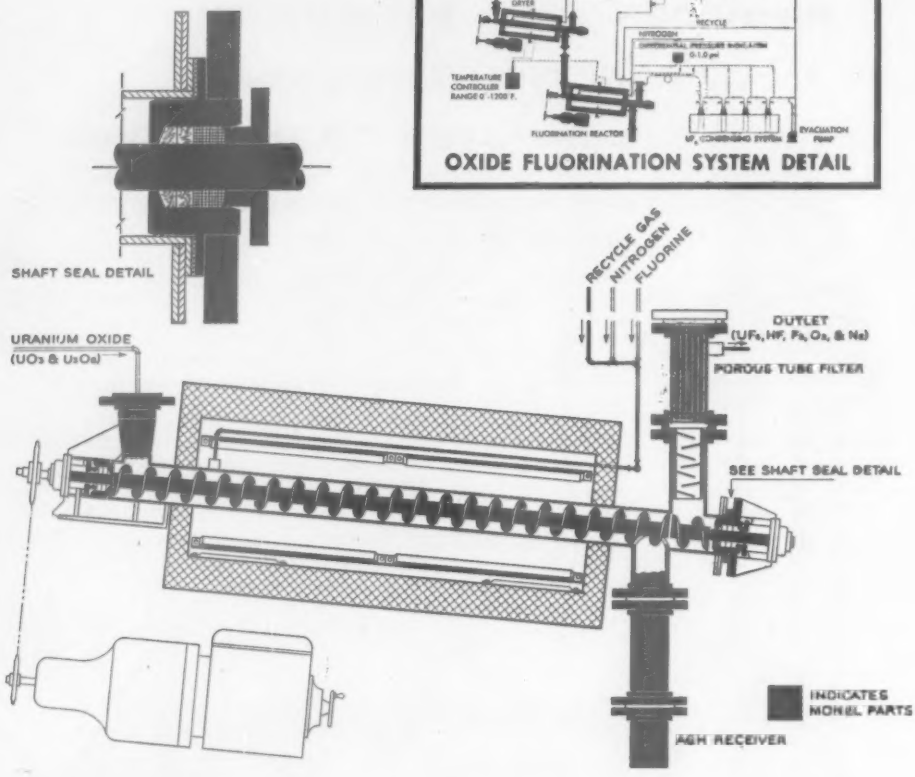

Corrosive conditions – To get an idea of the corrosive conditions faced by Monel alloy in this unit, look first at the small schematic. A dryer (same design as the fluorinator but made of nickel-containing stainless steel) feeds dry UO_3 and UO_3 to the fluorinator. The Monel screw carries the oxides into the hot zone. Here it is reacted at 1050°F with 98% fluorine. Outgoing gases (UF_6, F_2, O_2, N_2 and trace HF) are filtered and passed through Monel piping to condensers where refrigeration separates UF_6.

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And that goes for *mechanical design* as well as corrosion prevention. Take the fluorinator shown above, used in the uranium recovery unit at Oak Ridge. In the unit, uranium oxides are reacted with hot fluorine to form uranium hexafluoride. Wherever hot fluorine contacts metal, Monel alloy is used.

From the viewpoint of corrosion resistance this application of Monel alloy is not surprising. Monel alloy stands out in its resistance to corrosion by fluorine and its compounds. Hot or cold. Liquid or gaseous.

From the viewpoint of mechanical design, the versatility shown by this useful alloy is illuminating. Monel is used: (1) in Schedule-40 seamless pipe form; (2) as a welded fabrication (the screw); (3) for shafting; (4) in machined castings; (5) for piping. (See diagram above)

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Fusion: A Challenge to Universities

With the 1958 Geneva atoms-for-peace conference several months behind us, there has been ample opportunity to reflect on the implications of the total picture of fusion progress that was presented at Geneva.

Because of the sober views that prevailed, much of the glamour of fusion has been washed away. It is now generally recognized that, despite the somewhat hysterical unrealistic buildup before Geneva, practical and economic fusion devices are probably many years away. And so, although success in fusion would still have great significance on the international political scene and although there is still much bitter scientific rivalry in this field, it has been possible for the scientists to go back to work without most of the unhealthy pressures that existed before Geneva.

A major contributing factor to this new environment is the total declassification that now exists, at least in the Western world. Prior to Geneva it was felt by at least the U. S. that secrecy was necessary for two reasons: a fusion device might be a profuse source of neutrons, which would be useful to produce fissionable material for weapons; and a successful fusion device might have important economic impact and usefulness.

When it became apparent that fission reactors were mushrooming around the world and that they would equally well make neutrons available, and when it also became apparent that an economic fusion device was not just around the corner, the secrecy barriers were dropped.

Here then is the challenge to the scientific community: There are no more secrets in fusion. The goal is a vital and rewarding one. The problems are tough. And the time scale is long.

What is needed is a many-pronged attack. Because of the need to increase support of research in other areas, the government-supported effort in the U. S. is expected to continue at about the same rate as at present, barring any indication of a breakthrough. Presumably the effort of private industry will not be stepped up appreciably either.

The void in the program thus far has been in independent contributions from universities. Secrecy was, of course, the big deterrent. Now the setting is ideal. The field is in its infancy. No one starting in it now need feel that he's very far behind. The problems are ones of basic science that may have important ramifications in areas other than fusion. And there's no secrecy.

Also, the kind of fusion research that universities might do in graduate schools does not have to come expensively. For example, much needs to be done on plasma physics, theoretical and experimental.

It is our impression that the Atomic Energy Commission would welcome thoughtful proposals from universities that would broaden and strengthen the attack on fusion. New ideas are needed. What better source of them than the unfettered, free thinking of universities.

The challenge is there, only to be picked up.

Jerome D. Luntz

The recent operation of the Experimental Boiling Water Reactor (EBWR) at more than three times its design-power level and the prospects of reaching still higher power outputs have aroused interest and speculation about the present competitive status of boiling reactors for commercial power plants.

In this article, two authors with considerable boiling-reactor experience present their estimates for the performance and costs of boiling reactor plants that could be built today, based on the latest EBWR experience. J. M. West was project manager of EBWR at Argonne National Laboratory throughout the design, construction and early operational phases. More recently he has been in charge of boiling-reactor design work at the General Nuclear Engineering Corp. G. M. Roy played a prominent role in design of the Dresden and Pacific Gas and Electric boiling-reactor plants with the General Electric Co. before joining GNEC.

Analysis of EBWR Performance Clarifies . . .

The Future of Boiling-Water Reactors

By J. M. WEST and G. M. ROY, *General Nuclear Engineering Corp., Dunedin, Florida*

IN 1954, WHEN THE DECISION to build EBWR was reached, only very limited performance data were available for water-cooled reactors with steady-state boiling (*1*). Such data as did exist, however, were nevertheless encouraging.

Although the maximum power level achieved in the Borax I reactor (1,200 kw at a pressure of 130 psig) represented a power density of only 10 kw per liter of reactor core, Borax I was known to be a low-pressure machine not designed for high power density. Considerably better performance was expected in a reactor such as EBWR operating at 600 psig and designed with higher power densities as a primary objective. Nevertheless, in the atmosphere of uncertainty that prevailed during the design of EBWR, it was inevitable that the estimates of ultimate performance would be conservative.

From the beginning, EBWR was intended to be a completely integrated demonstration of a direct-steam-cycle, natural-circulation boiling-reactor power plant on a scale that could be extrapolated to sizes of economic interest for central-station power plants. The heat and electric outputs of 20,000 kw and 5,000 kw (*2*) were regarded as the minimum outputs from which extrapolations to larger plants could be made with confidence. These values were, therefore, adopted as the guaranteed design-output objectives of the EBWR.

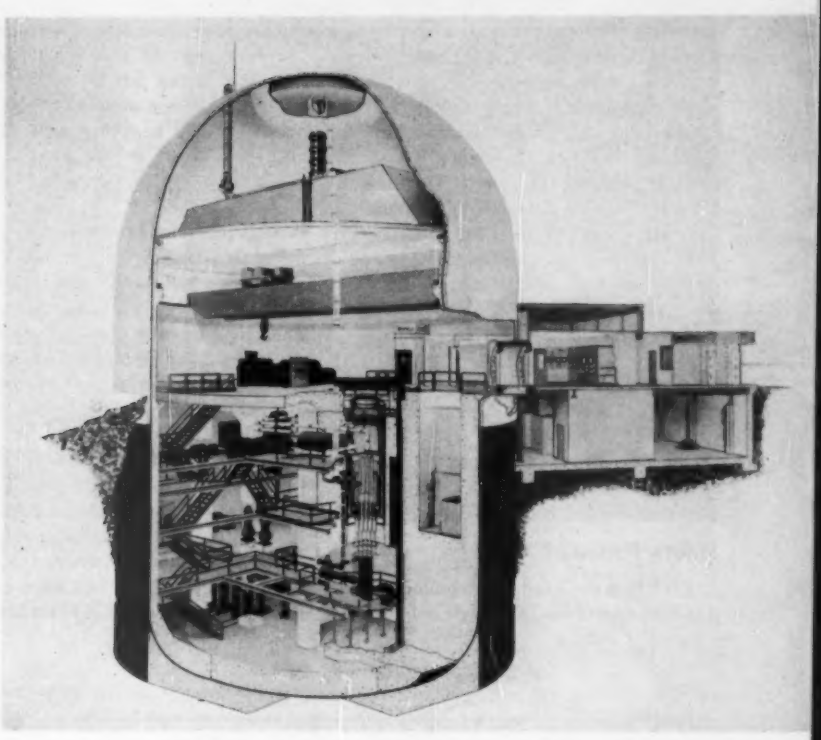
Although the Borax reactors utilized highly enriched U^{235} as fuel, it was clear that an economic nuclear power plant must use low-enrichment fuel. The change from the thin, fully enriched, high-thermal-conductivity fuel plates used in the Borax reactors to the thick, low conductivity, slightly-enriched-uranium plates used in EBWR introduced a major uncertainty concerning EBWR stability. EBWR pressure was set at 600 psig because Borax experience had indicated higher power densities and improved stability as the pressure was increased.

Power Operation

EBWR reached slightly more than its rated output of 20 Mw of heat and 5,000 kw of electricity on December 29, 1956. Shortly thereafter it was operated briefly at 26 Mw while safety circuits were being checked.

The 26-Mw output was achieved without any signs of instability, even though the entire bank of nine control rods was inserted halfway into the core. The effect of these rods was essentially to reduce the active height of the core from 4 ft to 2 ft. This experiment, in which the average power density was 2.6 times the nominal design value, provided the first strong indication that the heat-output capability of EBWR might be several times the 20 Mw for which it was originally designed.

Argonne National Laboratory turned to the oscillator technique for testing



EBWR, now with over two years operating experience under its belt, is one of the major reasons for increasing optimism about boiling-water plants

stability to determine the maximum stable output for EBWR. As might be expected, a resonance was observed that had an amplitude and frequency that increased with power level (*4–6*). An approximate indication* of the power level at which unstable operation will occur can be obtained by plotting the reciprocal of the gain at resonance frequency against the power level and noting where this curve extrapolates to zero (*4*). The ANL experiments and their analysis predicted that instability would not be reached in EBWR until a power output of about 65 Mw had been reached. Following the oscillation tests, EBWR was actually operated briefly at 61.7 Mw on March 20, 1958, without encountering instability.

The power output of 61.7 Mw(th) was reached in EBWR with the same number (114) of fuel assemblies in the core as the original loading. The only modification of the original EBWR was to replace two natural-uranium fuel assemblies at the center of the core with two assemblies enriched to 1.44% U^{235} to provide the reactivity needed to compensate for greater steam-void volume at higher power output.

At 61.7-Mw heat output, the average power density in the coolant channels of the EBWR core was about 75 kw per liter. The total uranium content of the core is 6.1 tons. The average specific power was, therefore, about 10 Mw per ton of uranium. The total flow (natural convection) of water through the core was about 10,500 gpm. The amount of reactivity held in steam voids was estimated at about 4% (*6*).

The highest power density in EBWR occurs in the central zone of the core where only thin-plate fuel assemblies

These Conclusions Emerge

1. Both EBWR and Borax IV are stable in operation even though they have much more reactivity invested in steam voids than did earlier boiling reactors. (The higher reactor pressure and/or long thermal-time-constant fuel apparently make this possible.) The operation of these natural-circulation reactors at high steam-void fractions permits an increase in power density large enough to virtually eliminate earlier concern about power-density limitations in this reactor type.

2. To escape the U metal-water hazard, future boiling reactors will turn to UO_2 fuel. Since the oxide is half as dense as the metal, substitution of UO_2 in a natural-circulation boiling reactor would mean a substantial increase in core size for the same output.

3. However, for small reactors the larger core would still be less expensive than using forced circulation. In fact, small EBWR-type reactors appear to have the lowest capital cost [estimated at $300–350/kw(e)] of any reactor type.

4. In larger reactors the design modifications needed to maintain a high power density with natural circulation make forced circulation more economical. Large forced-circulation plants if built today on U. S. industrial sites would cost $250–300/kw(e). There is hope that ultimately the cost will fall to $200.

* More rigorous feedback analysis procedures involving a large number of reactor parameters have been applied by ANL with considerable success in an effort to arrive at relationships predicting the stability of EBWR and other reactors.

are used. The water channels between these thin plates are 0.453 in. wide as compared with 0.388 in. wide for the thick-plate assemblies used in the outer zone of the core. Based on measurements of the void coefficient of reactivity during the startup of the EBWR, thin-plate assemblies could have been used throughout the core. If this were done, the average power density at 61.7 Mw would decrease from 75 to 70 kw per liter of coolant within fuel assemblies. The equivalent hydraulic diameter of fuel channels throughout the core would then be 0.804 in. This average power density of 70 kw/l in 0.804-in.-equivalent-diameter coolant channels is the most meaningful measure of the maximum performance of EBWR attained yet.

Future Potential

EBWR is designed to accommodate 148 fuel assemblies, although only 114 assemblies have been loaded thus far. If the additional 34 assemblies were loaded, the power output might be expected to increase approximately in proportion. The heat output would then be

$$(61.7)(148)/114 = 80 \text{ Mw(th)}$$

This increase in output requires a higher water velocity in the annular downcomer, which could conceivably cause entrainment of quantities of steam, which in turn would adversely affect the natural-circulation cooling. Until the experiment is done, one cannot be sure of the result. An 80-Mw(th) output is not considered an unreasonable expectation, however.

The EBWR core structure could also accommodate fuel assemblies of greater active length. For example, new fuel assemblies could be constructed with an active length of 5 ft but otherwise identical to the present 4-ft assemblies. If 148 such assemblies were loaded, the core would be about 5 ft in diameter and 5 ft high. At the power density already achieved in the 4 ft core, the total heat output would be (61.7)(148)(5)/(114)(4) = 100 Mw(th).

Whether a heat output of 100 Mw can be reached, with adequate margins of safety, in the present EBWR pressure vessel is a matter for speculation. There is a good chance for success. The reduced ratio of riser height to core height and the reduced downcomer area per unit of power output are certainly harmful to the natural-circulation process, however, and successful operation at 100 Mw(th) cannot, therefore, be guaranteed.

100-Mw capital cost. If the 100 Mw of heat output could be achieved in the present EBWR reactor, the gross electric output would increase to about 24,000 kw(e). The additional generating, heat dissipation and electrical equipment would probably cost about \$100/kw or $\$1.9 \times 10^6$ more than the present EBWR. When this amount is added to the adjusted EBWR cost when built today by private industry at a new site (see appendix), the total capital cost becomes: $\$6.01 \times 10^6 + \$1.90 \times 10^6 = \$7.91 \times 10^6$ or $\$7.91 \times 10^6/24{,}000 = \$330$/kilowatt.

Further simplification. Some costs incurred in the design and construction of EBWR could be avoided if a duplicate plant were built today. Extra costs incurred to hasten the completion date fall into this category.

Experience gained in building and operating EBWR also suggests design modifications that would reduce the costs. For example, the containment building could be made smaller, and nickel plating of the turbine could be eliminated. Blast-protection provisions are exaggerated in EBWR relative to other water reactors and substantial savings could result from eliminating or simplifying these design features.

Although the amount of saving would depend upon the particular circumstances, a saving of as much as 10% would not be surprising. If so, the cost per kilowatt based on the 61.7-Mw heat output already achieved in EBWR would be reduced from \$472 (see appendix) to \$425. The corresponding reduction for the case of 100-Mw heat output (if this proves to be successful) would be from \$330 to \$300/kw.

EBWR Core Design

The EBWR* core structure is centered in a pressure vessel with an inside diameter of 7 ft. It was expected that a core 4 ft in diameter and 4 ft high containing 112 fuel assemblies would be able to produce at least the 20-Mw-design heat output. In the literature, this 4-ft core has been called the "reference core." However, the core-support plate and shroud structure were designed to accommodate up to 148 assemblies to allow experimental variations in core loading and determine reactor performance under a variety of conditions, including testing with D_2O substituted for H_2O.

Each fuel assembly in EBWR contains 6 plate-type elements of uranium metal clad with Zircaloy-2. The uranium meat is alloyed with 5% zirconium and 1.5% niobium. Some of the assemblies contain natural U while other assemblies contain 1.44% enriched U. Some assemblies of each enrichment have fuel plates with a thickness of 0.214 in. (including 0.040-in. Zircaloy cladding) while other assemblies have plates with a thickness of 0.279 in. Characteristics of these four types of fuel assemblies are summarized below. The locations of the various types of assemblies in the core loading used during the early operation of the EBWR are shown in Fig. 2.

Characteristic	*Fuel assembly type*			
	Thin, natural	*Thick, natural*	*Thin, enriched*	*Thick, enriched*
Designating symbol	T	H	ET	EH
U^{235} content (%)	0.72	0.72	1.44	1.44
Meat thickness (in.)	0.174	0.239	0.174	0.239
Plate thickness (in.)	0.214	0.279	0.214	0.279
Average water-channel thickness (in.)	0.453	0.388	0.453	0.388
H_2O volume/U volume	4.416	2.759	4.416	2.759
Grams of U^{235} per assembly	291	413	582	826

* For general descriptions of EBWR design see references *2* and *3*.

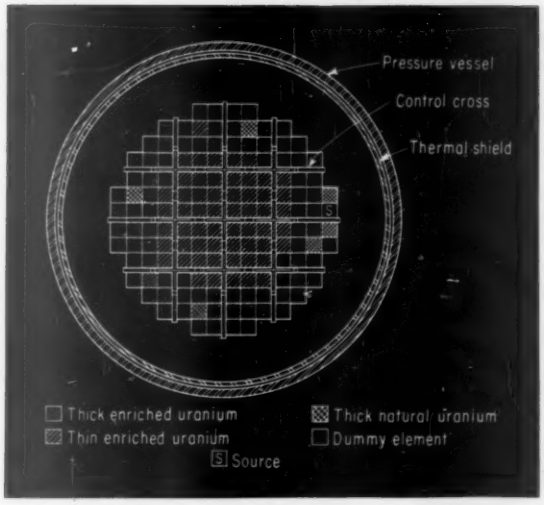


FIG. 2. Present EBWR loading with 114 U-metal fuel-plate assemblies achieved 61.7 Mw(th)

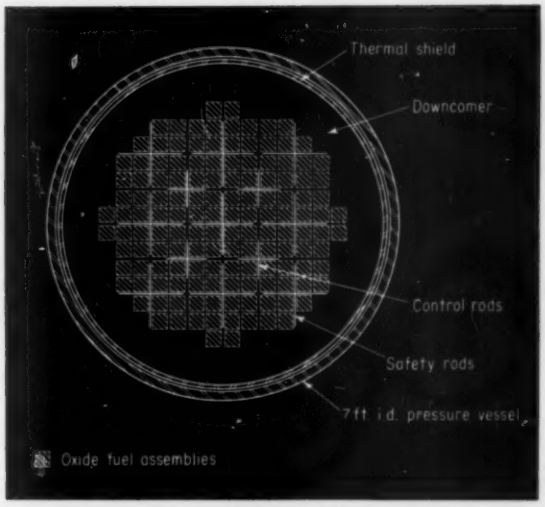


FIG. 3. Proposed loading with 140 UO_2-rod assemblies would reach 62.5 Mw(th) with 0.564-in.-diam rods

Even if it does not turn out to be feasible to generate 100 Mw of heat in the EBWR pressure vessel with natural circulation, this heat output could certainly be achieved in a slightly larger vessel at only a modest increase in cost. Provisions for ensuring the 100-Mw heat output should certainly not increase the cost more than 10%. Thus the cost of a 24,000-kw electric plant using an EBWR type of reactor is estimated to be in the $300–$330/kw range.

It should be emphasized that the $300–$330/kw cost applies to a duplicate of the EBWR plant and, therefore, includes no allowance for a large design effort such as would be required if the EBWR design were altered in any major way. Also not included are any allowances for profit or unusual circumstances.

Compared with the prices for other reactor types, this is a rather attractive price for a boiling-reactor power plant of 24,000 kw(e) output. If further experiments at Argonne show that 100-Mw heat output can be reached in the EBWR with natural circulation, this reactor will be very attractive for commercial application. Future plants of this kind will include certain design changes to take advantage of the knowledge accumulated since the EBWR was designed. For the most part, however, these modifications improve the reliability of the fuel and the plant rather than markedly reduce the capital cost. Major reductions in capital cost must come about mainly through increases in plant size or changes in basic characteristics such as addition of fossil-fueled or nuclear superheat.

Oxide Fuels

If cladding failures ever occur in EBWR fuel plates, the uranium alloy meat could be expected to oxidize rapidly, possibly resulting in highly objectionable contamination of the system. Although a great deal of effort has gone into attempts to devise metallic-uranium fuel elements that have satisfactory dimensional stability under irradiation, resistance to corrosion in hot water, and satisfactory neutron economy, no element satisfying all of these requirements has yet been developed. The U-Zr-Nb elements used in the EBWR have good dimensional stability, but the heat treatment required to provide this stability essentially destroys the corrosion resistance of the alloy.

Failure to develop a satisfactory metallic element has led to an almost universal trend toward UO_2 as the fuel in water-cooled reactors. If a new fuel charge were fabricated for EBWR, it would probably use UO_2 or ThO_2.

However, we shall see that the power output from a core of given size with natural-circulation cooling becomes significantly less when UO_2 fuel is substituted for the EBWR fuel. While the resulting economic penalty is not severe for small-size natural-circulation reactors, larger plants are put at a disadvantage compared with forced-circulation systems.

Oxide performance limits. Although UO_2 has excellent corrosion resistance in water, its low density and poor thermal conductivity are significant disadvantages. The principal effect is to reduce the hydraulic diameter, thereby reducing the maximum power that can be achieved with natural circulation. This is the result of the following two considerations:

• Temperature coefficient. In a boiling reactor, the upper limit of water-to-fuel ratio is usually set by the requirement that an increase in temperature or void should produce a loss in the reactivity. For a given core size, the volume ratio of uranium to H_2O will have to be approximately the same when UO_2 is used as when metallic uranium is used. Since the uranium density of UO_2 is only about 48% that of metallic uranium, the reactor-core volume occupied by the required amount of UO_2 is much greater. Hence the space available for H_2O coolant is correspondingly reduced.

The greater leakage of neutrons from a small reactor tends to make the void coefficient of reactivity more negative and, therefore, allows the

water-to-fuel ratio to be greater than would be permissible in a large reactor. Thus, the fraction of the total core area available for coolant circulation can be greater in a small reactor than in a large one.

• Increase in subdivision. The temperature drop from the center of the fuel T_c to the surface T_s is given by $T_c - T_s = q_v/4kR^2$, where q_v = heat generation/unit volume, k = thermal conductivity and R = rod radius. This equation shows that the allowable heat generation per unit volume is dependent upon the product $k(T_c - T_s)$. This product, for an operating pressure of 1,000 psi, is about 40% larger for uranium metal than for UO_2. This is in spite of the very high allowable temperature (about 5,000° F) for UO_2 against an allowable maximum of 1,200° F for uranium metal. The reason is that the thermal conductivity value for UO_2 is only 1.1 Btu/(hr)(ft)-(° F) as compared to about 16 for uranium operating at high temperature. To compensate for this, UO_2 must be more finely divided. Thus the fuel-element-rod radius would have to be reduced when substituting UO_2 for U metal. In addition to reducing the hydraulic diameter, this also tends to increase the cost of fuel fabrication.

Effect on core design. To illustrate the effect of UO_2 fuel on reactor design, we have developed conceptual designs of new cores that could be used in pressure vessels of the EBWR size (7-ft dia).

The "new" core for EBWR is taken to be 5 ft in diameter and 5 ft high. We have already shown in this article that a power output as high as 100 Mw might be achieved in a core of this size loaded with EBWR metallic plates.

A cross section of the new core is shown in Fig. 3. We have taken the liberty to change the lattice to allow more control rods to be used. The number of control cruciforms is 13 as compared with 9 in EBWR. Some of these rods would enter the core from the bottom to allow better shaping of the power distribution within the core. The larger number of rods will also give additional control margin for long fuel exposure.

A total of 140 fuel assemblies are used in the 5-ft core. Each of these assemblies is in the form of a 4-in.-square Zircaloy-2 box. Four such boxes occupy the 8¾-in.-square grid cells between control cruciforms. The control cruciforms are on a 9-in.-square lattice.

The total amount of UO_2 used in the core is fixed by the requirement that the core have a slightly negative steam-void reactivity coefficient at room temperature. All of the designs considered here have a volume ratio of H_2O to UO_2 in the core of 2.20. This is just slightly greater than the corresponding value (2.12) in the central region of the EBWR, the increase being justified by the greater resonance absorption of neutrons in the highly subdivided UO_2 fuel.

Although the ratio of H_2O to UO_2 in the core is fixed by nuclear considerations, the amount of subdivision of the UO_2 can be altered to give the specific power desired—i.e., as noted previously, the rod diameter can be adjusted to hold maximum temperature to a specified value. This was chosen as 4,500° F. Three different rod sizes were compared with the performance of the EBWR core using metallic uranium. Arrays of 5 × 5, 6 × 6 and 7 × 7 fuel rods per fuel assembly were used as shown in Fig. 4. The H_2O/UO_2 ratio is the same for all three of these variations and, as noted above, is 2.2 for the over-all core. The value of the ratio within the grid cell is 2.01.

The results in the table show that in attempting to reach higher specific power in the fuel, the equivalent hydraulic diameter is significantly reduced. Even when using the largest rods with a power output of only 62.5 megawatts, the equivalent diameter is only 76% that in the present EBWR. The greater resistance to flow raises doubts about the ability of the cores using UO_2 fuel to achieve power densities comparable with EBWR under natural-convection cooling. This is especially true of the cores using the 36-rod and 49-rod designs.

Another approach toward alleviating the central temperature limit is to use a cored UO_2 fuel design, i.e., a design that has a hollow center with cooling on the outside only. This serves to reduce fuel temperature, but only at the sacrifice of reducing hydraulic diameter. Therefore, again *for a given core size*, the UO_2 design would have greater flow resistance.

Forced circulation vs. larger core. The greater flow resistance associated with UO_2 fuel introduces serious doubts about whether oxide cores can reach the 70 kw/liter (average) already achieved in EBWR. The power density could always be increased by using forced circulation.

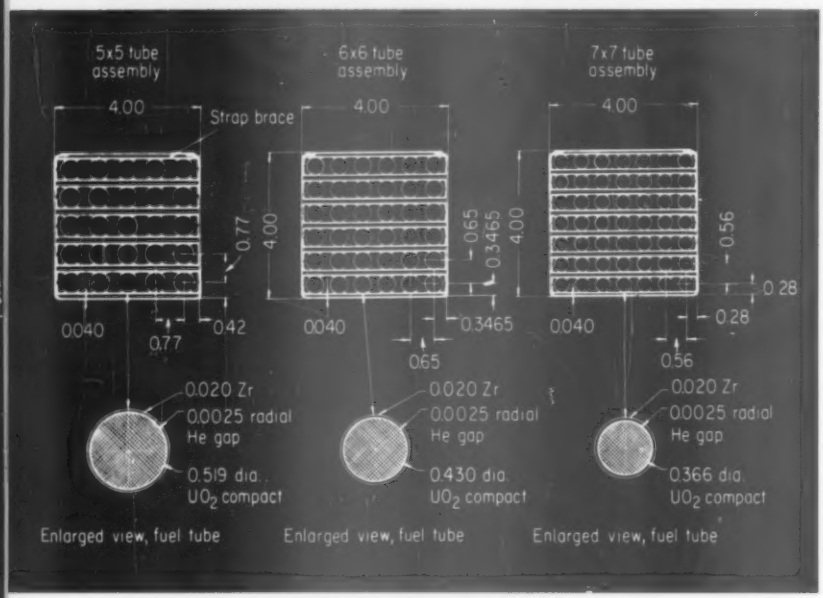


FIG. 4. Fuel assembly designs for three sizes of UO_2 rods

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An alternative is to make the core (and the pressure vessel) large enough to achieve the power output without exceeding the power density possible with natural circulation. For example, a 5.5-ft-dia 5.5-ft-high core using UO_2 fuel and natural-circulation cooling should be roughly comparable in power-output capability with a 5-ft core using EBWR-type metallic fuel. Thus this approach means only a slight increase in pressure-vessel diameter and height. Since the pressure-vessel size would still be well within present fabrication and transport capabilities, this alternative appears more economical than forced circulation.

The major problem associated with natural-circulation cooling in reactors whose power output must be guaranteed is that the performance under natural circulation cannot be predicted with accuracy. At the present state of knowledge, natural-circulation core designs must inevitably be developed on a more conservative basis than would be necessary if forced circulation were used. Nevertheless, EBWR experience at high power density with natural circulation shows that natural circulation will be more economical than forced circulation in small reactors.

Large Reactor Plants

As already mentioned, the power output of a natural-circulation core can be made equal to that of a forced-circulation core by making the core and pressure vessel larger. As the power level is increased, the pressure vessel ultimately reaches the practical limit in size from the standpoint of fabrication and transportation. This limit would correspond to lower power levels for natural-circulation than for forced-circulation reactors.

Multiple reactors of the natural-circulation type could be used to produce the same power output as a single forced-circulation reactor, but this would result in higher total cost for the electricity produced. Both capital and operating costs would be higher with the multiple units, particularly if safety requirements dictated that each reactor be housed in its own individual gastight containment vessel.

Moisture separation. As core heights are increased while maintaining the same power density in the core, the velocity of steam in the upper part of the pressure vessel increases correspondingly. For very large cores, the upward velocity of steam is too great for gravitational separation of moisture from the steam to be effective. The limiting value of steam velocity is not known accurately at present, however. When operating at 61.7 Mw the upward velocity of steam in the EBWR is about 1.75 ft/sec. Available literature indicates that this may be near the limiting value.

It will be extremely important to observe the change in quality of the steam leaving the pressure vessel as the power output of EBWR is increased further. It may be that an additional external moisture separator of the centrifugal type will be required before a power level of 100 Mw is reached. (Although *internal* moisture separators can be installed in boiling reactors cooled by forced circulation, the pressure drop in such separators would be intolerable in a natural-circulation system.)

Good separation of steam and water is also essential to efficient functioning of the natural-convection cooling circuit. If steam were entrained in the downcomer water, the lower density would reduce the driving head for natural circulation. Subcooling of water entering the core would also be reduced, because quenching of the entrained steam would raise the water temperature. The steam-void content in the reactor core would, therefore, be greater than calculated on the basis of no steam entrainment.

The water-steam separation problem is another example of uncertainties arising in the design of natural-circulation boiling reactors. Solutions to this problem are available when forced-circulation cooling is used.

Because of the higher water-coolant velocities required, the water-steam-separation problem and the desirability of achieving the total required heat output in a single reactor pressure vessel, forced circulation will be more economical than natural circulation in large boiling reactors.

Subcooling. Power densities can be increased without exceeding tolerable limits on steam-void fraction either by increasing pumping or by using subcooling. The choice is an economic one and is largely determined by the allowable limit on steam-void fraction. For very large reactors, subcooling with forced convection usually proves to be best. Since the power density and power level at which subcooling proves economically advantageous depend on allowable steam voids, the lower this limit the lower the power level at which subcooling proves advantageous.

In a direct-cycle boiling reactor of the EBWR type, significant subcooling results from introduction of condensate from the main condenser into the recirculating coolant in the reactor. About one-third of the reactor heat is required to raise the temperature of the coolant to its boiling point. In other reactors, the nonboiling fraction of the reactor is increased by operating at a higher pressure and/or by extracting additional heat from the coolant in external heat exchangers. Although there is no universal agreement among

UO_2 vs. U-Metal Core Parameters for EBWR

	Metal core (present)	*Oxide core*		
Rod lattice size		5 × 5	6 × 6	7 × 7
Diam of UO_2 compacts (in.)		0.519	0.430	0.366
O.D. of Zr tubes (in.)		0.564	0.475	0.411
Equivalent flow diam within assemblies (in.)	0.804	0.612	0.520	0.452
Total flow area within assemblies (ft^2)		8.86	8.74	8.60
Total power level of core (Mw)		62.5	90.0	123.0
Average power density in H_2O within grid cells (kw/liter)		44.2	62.5	86.6
Average power density in H_2O within assemblies (kw/liter)	70	50.0	72.7	101.0
Specific power (Mw per ton of U)		8.70	12.7	17.6
Maximum heat flux with 4:1 peak average (Btu/hr-ft^2)		330,000	392,000	456,000

boiling-reactor designers regarding the optimum amount of heat to remove in heat exchangers, most large boiling reactors use heat exchangers for a substantial amount of subcooling of the recirculating water.

Significantly, once a decision is reached to pass reactor cooling water through heat exchangers, a major part of the cost of forced circulation has already been incurred. Thus for large boiling-reactor power plants in which heat exchangers are used for subcooling, forced circulation appears to be superior to natural circulation.

Large plant costs. As in other types of reactors, the capital cost per kilowatt of electric output decreases as the size of the boiling-reactor power plant increases. The significant advantage in capital cost enjoyed by boiling reactors relative to other types for small plants is also apparent in very large plants. This advantage is a direct result of the inherent simplicity, safety, and high efficiency of the boiling system.

We have already given a cost range of \$300–\$330/kw(e) for boiling-reactor power plants of about 24,000-kw(e) output built today at typical U. S. A. industrial sites. For a plant with an output of 200,000 kw(e), the capital cost at present would be in the range of \$250–\$300/kw. As more experience accumulates with boiling reactors, the capital cost on very large plants may ultimately reach \$200/kw(e).

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APPENDIX—Cost of Duplicate EBWR

Actual cost of EBWR. The cost of building a duplicate of EBWR at ANL has been estimated (*3*) at \$4.629 × 10^6. This figure is based on actual cost records for the EBWR project at ANL. Expenses incurred for research and development for EBWR and for facilities to permit experimental operation with forced circulation and with D_2O were properly excluded, since such expenditures would not be required for a duplicate plant designed to operate only with H_2O and with natural circulation.

In this article, our objective is to interpret the EBWR performance in terms of what boiling reactor plants built by private industry at nongovernment sites would cost. To do so requires adjustment of EBWR costs for differences in accounting practices, site conditions, and escalation factors as well as power output.

Cost of EBWR at an industrial site. Some of the facilities such as roads, power lines, water lines, sewers, offices, etc., which were already available at ANL would have to be built at a new power-plant site. The cost of these items would be significant. Those items of reactor equipment fabricated or installed by ANL shop and/or field personnel would be considerably (~30%) more costly if this work were done by private industry. This difference is mainly a result of differences in accounting practices. A profit is also normally included in an industrial rate. The writers believe that the combination of site conditions and labor costs would make a plant built at a new non-government site about 10% more expensive than an identical one built at ANL. The base cost of the EBWR will therefore be increased by 10%:

$$(\$4.63 \times 10^6)(1.10) = \$5.09 \times 10^6$$

Escalation of EBWR costs. Three years have elapsed since construction of the EBWR began. If the same plant were built now, an escalation factor of about 1.18 (6% per year for 3 years) should be applied. The estimated cost of building the duplicate EBWR at a new non-government site, beginning now, is therefore:

$$(\$5.09 \times 10^6)(1.18) = \$6.01 \times 10^6$$

Cost for 61.7-Mw output. It will be assumed that the 61.7-Mw output achieved in EBWR thus far represents a safe power level for steady operation in a commercial power plant. Although this output might be uncomfortably close to the level of instability for the present core containing 114 elements, it is practically certain that removal of the 34 dummy assemblies and addition of a few active assemblies would make 61.7-Mw output completely satisfactory for steady operation.

With 61.7-Mw output in the form of 600 psig steam, EBWR should be capable of generating about 14,800 kw of electricity. The present 5,000 kw turbo-generator could be replaced by one of 14,800 kw capacity. Supplemental condenser, pump, transformer and cooling tower capacity would also be needed. For the 9,800 kw increase in generating capacity, an additional investment of about \$100/kw is estimated. This would involve an additional expenditure of \$0.98 × 10^6. This amount added to the \$6.01 × 10^6 original cost would raise the total cost of the 14,800-kw EBWR to \$6.99 × 10^6. Per kilowatt of gross electric output the capital cost would then be calculated as follows

$$\frac{\$6.99 \times 10^6}{14{,}800} = \$472/\text{kw}$$

The \$472/kw figure for a 14,800-kw boiling reactor power plant of the EBWR type built now at a nongovernment site is based on actual EBWR operating experience and adjusted cost experience. It is, therefore, considered to be free of speculative risks, financial or otherwise.

Comments by EBWR Project Supervisor J. M. Harrer

Although the authors have presented a worthy discussion of boiling reactor possibilities, some clarification might be in order on a few points.

Early operation. The authors point out that in the 26-Mw tests, the power density was 2.6 times design. The records show the number to be 25 Mw during these shutdown circuit tests, which would imply a 63 Mw possibility. This seems to foreshadow the 65 Mw predicted by more refined methods, but tends to be misleading.

In reference *6*, we pointed out that for EBWR the slope of the curve of the void reactivity vs. power output was less at higher powers. This effect alone probably produced more confidence in higher power possibilities than any other single measurement.

In BORAX IV, this curve slope increased near the point where chugging instabilities set in. These ideas are quite thoroughly discussed in reference *6*.

The amount of K in voids is no longer considered the power controlling factor. It is the rate at which voids change with power increments which has led to the higher power stability. This was covered in reference *6*. It should be noted that the pressure of BORAX was not increased above 300 psig. The high K in voids was reached in that reactor.

Maximum-power output prediction. In the same reference *6*, the meaning of transfer function measurements was discussed. It was shown that the resonant peak observed was not related to instability by any straight line approxima-

tion. If plotting the inverse peaking vs. power predicts stability, it may be merely a coincidence, since feedback theory does not verify this approximation. It was emphasized that stability of a physical system must be given in terms of phase margin and amplitude margin to be meaningful.

The refined methods used in EBWR analysis produced not only the prediction of stability, but also much data which can be used in predicting the effects of parameter variation. It was shown, for example, that a longer fuel time constant could improve stability in EBWR. This is by no means a general conclusion. Oxide fuels will not necessarily produce greater stability in all reactors or reactor systems.

Cost of duplicate EBWR. It would seem more logical to start the discussion of cost of construction and cost changes with a basic estimate of the cost of a single-purpose plant.

To start with, EBWR costs, even adjusted, tend to get one off on the wrong foot when straight-line approximations are to be used to add up the costs for a higher plant output. One can question the application of the site development multiplier, 1.10. It is not clear why this should be a multiple of the base cost of EBWR, since it would be greatly affected by choice of site. The use of the escalation multiplier of 1.18 implies that the multiplier could reach 2.00 in 16.7 years. If this is true, then orders for plants had better be placed soon.

Adding the $100 per kw of increased capacity is a matter clearly up to the estimator. This reverts back to the idea suggested here of preparing a new base cost estimate.

Future potential. In speculating on a new design, one could choose to extrapolate from 65 Mw, which in a 5 ft × 5 ft core (properly designed) leads to a 110 Mw(th). At 28% plant efficiency, this would allow an output a little over 30 Mw(e), which was used as a cost basis in reference *6*. In that paper, we admitted that the cost estimates were speculative, but they were a current estimate based on commercial equipment and not related to the original EBWR cost by extrapolation.

Oxide fuels. Oxide fuels, as the authors point out, create new problems, as well as yielding solutions to existing problems. The important factor is the power density in the coolant. Both EBWR and BORAX IV (an oxide-fueled unit) have reached over 70 kw per liter of coolant. Some investigators look toward 100 kw/liter as a reasonable objective in natural circulation. One can therefore be more optimistic about the natural-circulation system. The values given in the table in the paper very likely can be obtained when good design is provided in the reactor flow system. It is not necessary to go directly to forced circulation. In fact, one should consider just what advantage one can obtain from forced circulation.

It makes no fundamental difference how a pumping head is obtained, as long as the head is available. A good head of water in the downcomer will pump just as effectively as one provided in a mechanical pump. The choice is up to the engineers. If one takes heat out of the forced-cooling cycle, the pumping advantage is obvious. As the authors point out, the high power system will certainly require pumping. The point at which we must change from natural to forced circulation for economy or feasibility could be the break-even point between pressurized systems and boiling systems.

General. We were interested to note the usual dismissal of multiple small reactors as an uneconomical or costly replacement for a single large plant. One wonders if this is justified with an honest cost study. Why not build a plant you know how to build and with which you have experience, rather than argue that it must be extrapolated into the unknown to be worthwhile? Large coal plants produced lower labor cost, less maintenance, higher temperature and the resultant higher plant efficiencies. Nuclear plants present their own features and problems.

Maintenance cost on a reactor is so speculative that one should be afraid to mention a number. Operating labor for several reactors might be nearly the same as for one reactor, when one considers centralized control, waste disposal, effluent control, etc. associated with the nuclear and radiation features.

When coal burns, it produces high-temperature gases, which naturally lead to higher temperature steam and make higher plant efficiencies possible. The small low-pressure boiler was some 65% efficient. The large higher pressure and temperature unit yields over 90% efficiency. In the direct-cycle boiling reactor one can recover almost 100% of the heat produced in the core. On this basis, the reactor has already outperformed the boiler. Certainly a real effort to make use of this basic advantage is justified without complicating the picture with prejudice toward size, temperature or pressure. A nuclear power reactor is *not* "just another boiler," a remark frequently heard from power engineers.

We would like to recall the stand we took before on the effect of fuel-cycle cost on the cost of power. It is this cost which includes fabrication, utilization and reprocessing that will ultimately make or break nuclear power as a practical source of energy. One can get as much, if not much more, experience and improvement in this area from several small plants as from a single large plant.

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Authors West and Roy Reply

Mr. Harrer's comments are most welcome, and although not endorsing his views entirely, the authors have no serious disagreement with the essence of most of his comments.

We agree that considerable progress has been made toward showing that boiling reactor stability is basically a predictable phenomenon. Since the technical details could not all be covered in this paper, references have been suggested for the interested reader. An additional reference on the subject is GER-1468—a G. E. bulletin.

We believe the different viewpoint relative to capital cost extrapolation and interpretation is self evident. Costs given by the authors are indicative of the bid prices that might be obtained from industrial sources.

Mr. Harrer's comments relative to the future potential of natural circulation affords an opportunity for us to clarify our view relative to these and other similar comments received. It is emphasized that both forced circulation and sub-cooling were indicated as advantageous for 'large' plants. The authors purposely avoided giving a quantitative power level where natural circulation loses its economic advantage over designs capable of higher specific power. In fact, the authors reached an honest *disagreement* on this point.

We share Mr. Harrer's enthusiasm for boiling reactors of small size to the extent of agreeing that boiling reactors suffer less from being built in small sizes than do some other reactor types. Small boiling reactors can, therefore, be quite attractive for plants from which only a small amount of electricity is needed. However, the fact that there is an overall reduction in unit cost of electricity as the size of the boiling reactor is increased, within reasonable limits, seems to be well substantiated by cost data on plants already built, authorized, or planned.

—J. M. West
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Processing–Refabrication of Metallic-Uranium Fuel

During processing of irradiated fuel, not all of the fission products need be removed. Such low-decontamination processes offer simpler fuel cycles and lower over-all power costs

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IN POWER-REACTOR FUEL CYCLES, total removal of fission products and bred materials may not be necessary because the bred fissionable material may more than offset the loss of reactivity caused by the presence of the fission products. Low-decontamination processes, during which some, but not all, of the fission products and bred materials (such as Pu^{239}) are removed, may, therefore, offer an opportunity for simplifying power-reactor fuel cycles and reducing over-all power costs. Fuel processed by these low-decontamination methods is still highly radioactive, however, and necessarily requires remote handling throughout.

Low-decontamination processes have been studied at various sites (*1–4*). Argonne National Laboratory has been especially active in the development of melt refining for treatment of fuel from EBR-2, now under construction at National Reactor Testing Station, Idaho. The Processing-Refabrication Experiment (PRE) program (*5*) was initiated at Atomics International to mockup a low-decontamination process for irradiated uranium fuels.

Process Line

The PRE low-decontamination process is shown schematically in Fig. 1. Fuel elements (see Fig. 2) irradiated in an adjacent power reactor are transferred to a hot cell for disassembly, removal of NaK and preparation for delivery to a processing cell.

Access to the processing cell, which contains an inert atmosphere, is through a monitored vacuum lock. In the processing cell, the irradiated fuel is melted in a zirconia or magnesia crucible for removal of some fission products, notably the rare earths, as melting dross (see box), and for casting into an ingot. The ingot is remelted in a vacuum-casting furnace, where highly enriched uranium metal is added, and then centrifugally cast into cylindrical slugs. The slugs are cropped to length, faced at each end and inspected for dimensions, subsurface porosity and density. Accepted slugs are passed through a chute into an air-atmosphere fabrication cell.

In the fabrication cell, the recast slugs are reassembled into fuel elements. This consists in loading stain-

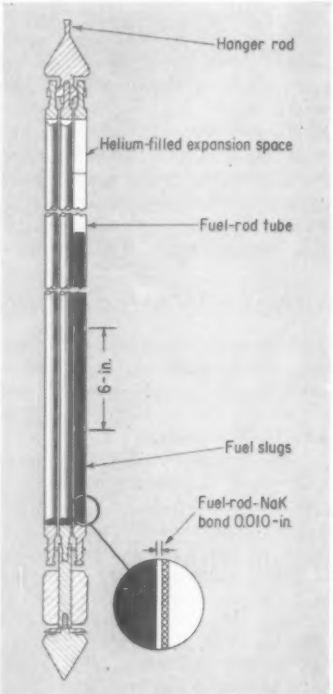

FIG. 2. Fuel element of type to be remotely fabricated in PRE facility

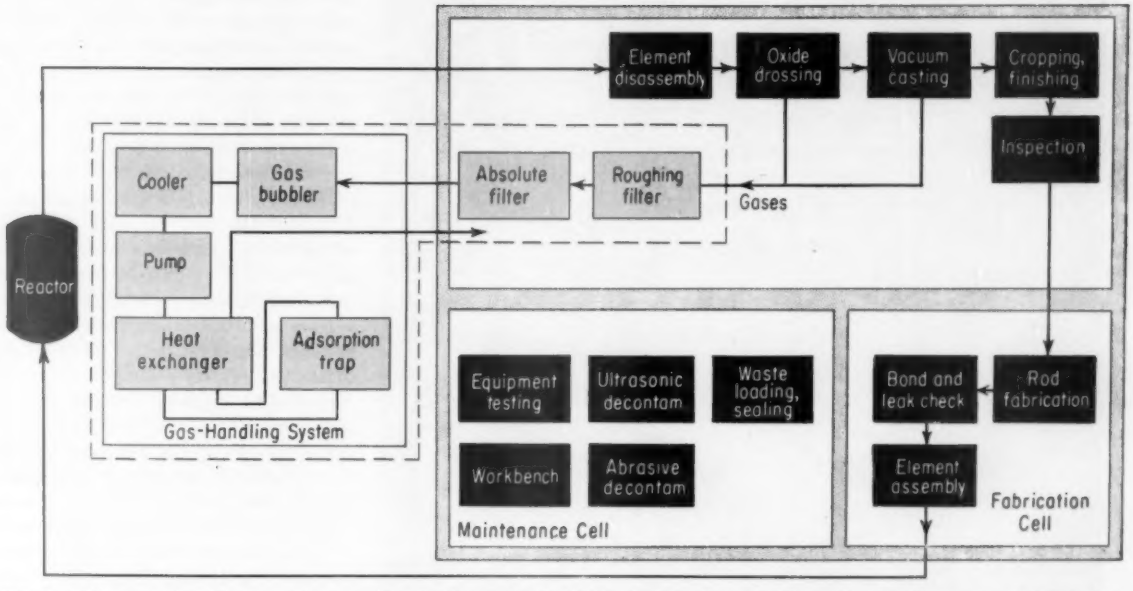

FIG. 1. Schematic flow diagram of process line for Processing-Refabrication Experiment facility. Gas-handling system is located in shielded vault below processing cell (upper right)

less-steel tubes with fuel slugs, filling with NaK to make a thermal bond between fuel and tube, topping off with helium and welding a cap on the tube. Sealed and inspected rods are clustered to form a fuel element that is returned to the reactor for a second cycle of irradiation.

A third cell in the complex is used for repair and maintenance of process and handling equipment, for equipment decontamination and for preparation of radioactive waste for disposal. Material and equipment are transferred to this cell through a monitored access lock.

Cell Mockup

The process and handling equipment for low decontamination and refabrication of irradiated metallic uranium were developed under simulated in-cell conditions in the mockup shown in Fig. 3. The purpose of this facility is to operate individual pieces of equipment and combinations of adjacent pieces of equipment only—not to mockup the integrated process line. This procedure ensures that each piece of equipment can be remotely operated and that transfer of material between adjacent pieces of equipment can be performed remotely.

The mockup includes prototype in-cell cranes and manipulators in a 10- by 30-ft area behind a 3½-ft thickness of plywood simulating the cell wall. Wherever possible, operations are viewed directly through a simulated shielding window mounted in the mocked up cell wall. Some operations are viewed indirectly with periscopes and a closed-circuit TV system.

For mockup purposes, the periscope, master-slave manipulators and shielding window can be moved directly behind any desired position along the simulated cell wall. In the actual cells, they will be fixed at positions in the cell walls that are determined by mockup results.

Equipment Development

A standard 30-kw induction furnace was modified by the addition of such remotely operable auxiliaries as off-gas filters, ducting to the gas-handling system, periscopes and a bridge breaker. This furnace is the prototype of an

Oxide Drossing Explained

Oxide drossing is a pyrometallurgical method for partial removal of fission products from irradiated metallic-uranium fuel. When irradiated uranium is melted in a zirconia or magnesia crucible, some of the metallic fission products, notably the rare earths, are oxidized to their respective oxides and separated from the melt in the form of a dross, or crust, which adheres to the crucible after the molten metal is poured. Other fission products such as molybdenum, zirconium, niobium and plutonium, whose oxides are less stable than uranium, are not oxidized or volatilized during melting. These metals remain as alloying constituents in the cast uranium ingot. During the melting operation noble gases and volatile metals are evolved and collected outside the melting furnace.

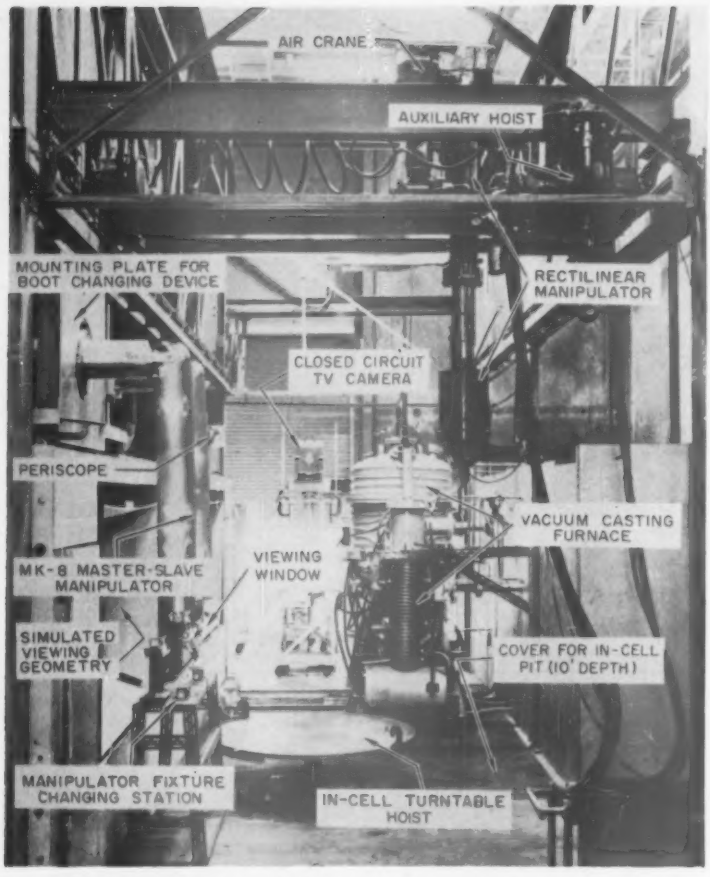

FIG. 3. PRE mockup showing prototype maintenance and repair workbench-turntable in lower center. Mockup arrangement does not simulate process line

oxide-drossing furnace (*5*) for removal of rare-earth fission products from irradiated metallic-uranium fuel in the actual facility.

The ingot mold shown in Fig. 4 consists of three separate pieces that are parted by a pneumatic cylinder. The ingot is stripped with a special grapple attached to the in-cell crane hook. The second bail on the ingot grapple is used to release the grapple after the ingot has been transferred to the vacuum-casting furnace.

The prototype oxide-drossing furnace and ingot mold have been used successfully in repeated cycles of simulated remote operation in the PRE mockup. The entire cycle, from remote loading of the simulated fuel slugs through melting, tilt pouring and mold stripping, takes about 2½ hr.

The prototype 50-kw vacuum-casting furnace (*6*) shown in Fig. 5 has been successfully operated remotely to cast simulated fuel slugs for the type of fuel element shown in Fig. 2. The furnace was designed to permit remote maintenance of many of its components. Modifications are proceeding to permit completely remote maintenance. In designing this furnace, all fixed connections, such as power leads and vacuum ports, were attached to the middle section. The top section can be removed with the in-cell crane so that the crucible and induction heating coil can be removed remotely, using only the crane, if repair or replacement is necessary. The bottom section, containing the centrifuge and drive motor, can be lowered by integral motor-driven jacks and rolled away to remove the centrifugal mold. In case of the failure of the integral jack motors, all motions can be actuated by an impact wrench attached to the in-cell crane hook.

During melting in the oxide-drossing furnace, most of the volatile fission products and noble gases are released. More may be evolved during remelting in the vacuum-casting furnace. These products are handled in an auxiliary, closed system to prevent their release into the cell atmosphere. A prototype gas-handling system has been built and partially tested (*7*). In this system, volatile elements, such as cesium, iodine, barium and tellurium, are collected by condensation on a roughing filter in the furnace hood and absolute filters in the gas ducting. Oxygen, nitrogen and hydrogen are removed from the furnace off-gas in an alkali-metal gas bubbler. Xenon and krypton are adsorbed on silica gel at liquid-nitrogen temperature. The stripped inert gas is returned to the process cell. Xenon and krypton are compressed and stored for partial decay of xenon before disposal. The silica-gel adsorption column is regenerated by heating to a slightly elevated temperature to release adsorbed xenon and krypton.

In the actual facility, it is planned to locate the gas-handling system in a partially shielded vault below the hot cells. The shielded vault will be accessible for contact (as opposed to remote) operation and maintenance of the gas-handling system.

A prototype device for fabricating simulated fuel rods was built and successfully demonstrated. Satisfactory leak-tight welds were consistently made. Further modification of this prototype equipment is under way to permit completely remote maintenance using only available in-cell tools and handling equipment.

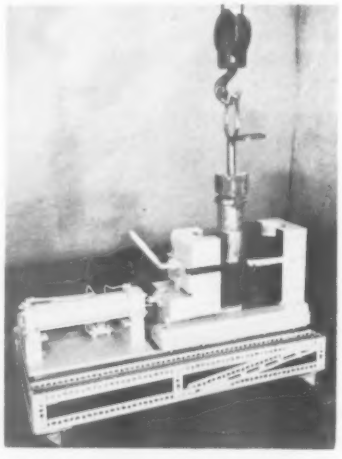

FIG. 4. Ingot mold for tilt-poured oxide-drossing furnace showing pneumatic device that separates parts

Maintenance and Repair

Only rudimentary maintenance operations are performed in the process and fabrication cells—failed equipment or components will be removed and replaced. The faulty unit is transferred to the maintenance cell in which a higher order of manipulative dexterity is provided. If a still higher order of manipulative dexterity is required than is possible in the maintenance cell, the equipment will be either discarded or decontaminated and removed from the maintenance cell for repair. The choice of alternatives will depend on the relative cost.

A prototype workbench-turntable (see Fig. 3) has been built and used in the PRE mockup for simulated in-cell maintenance operations. The table is capable of lifting the heaviest piece of in-cell equipment as much as 4½ ft and rotating it completely to bring all parts of the equipment into the window line-of-sight. Because the turntable is inaccessible for contact maintenance, it was designed so that all actuating gear and motor drives are located in a subcell room that is accessible for contact maintenance. The only in-cell component requiring servicing is a chevron-type sealing gland. This gland was designed so that it can be replaced remotely using only the maintenance-cell crane and impact wrenches.

Development of a method for servicing in-cell mercury-vapor lamps and helium-cooled luminaires from outside the cell was devised. The lamp and luminaire assembly is lowered to the cell floor by means of a rod extending through the shielded cell roof. In this position, they are serviced by in-cell cranes or manipulators. Continuous shielding is provided during the lowering operation by the lowering rod, and the integrity of the cell shielding is maintained by monitored seals. A pyramidal glove box is mounted on top of the cell roof while a light or luminaire is being serviced. When a burned-out lamp is to be replaced, the lowering rod is fed through a seal in the top of the pyramidal glove box and is attached to the top of the luminaire. In the PRE mockup, the complete cycle of changing a luminaire was successfully demonstrated using only remote devices (*8*).

A similar technique was demonstrated in the PRE mockup for servicing a failed crane bridge. The crane bridge was removed from its tracks, rotated and lowered to the cell floor where maintenance or part replacement could be performed.

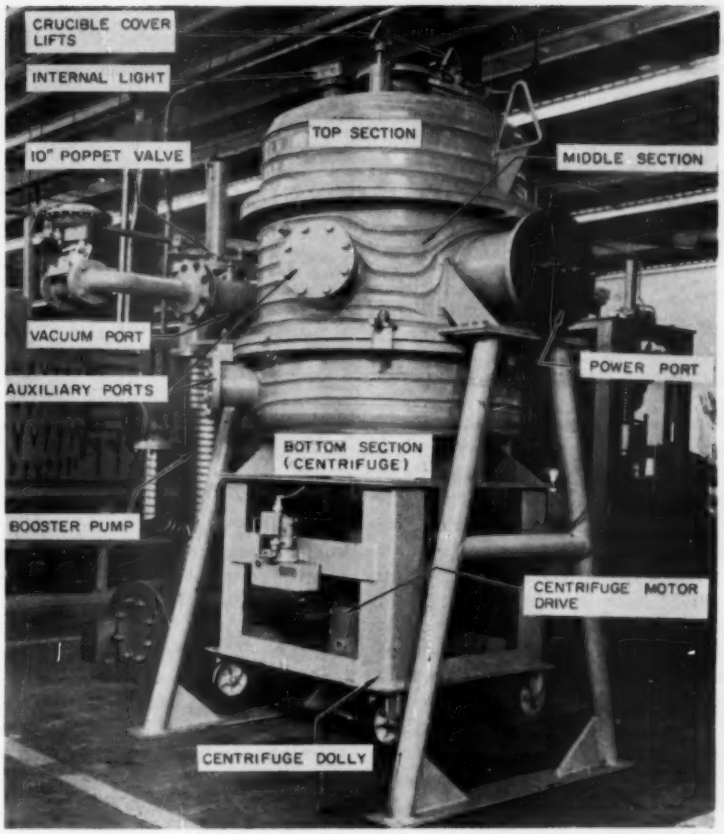

FIG. 5. Vacuum-casting furnace showing dolly mounted to bottom section, fixed connections attached to middle section and top section with brackets for lifting

The primary objective of the PRE mockup is the development of criteria on which the design of the actual facility and its equipment can be based. Successful demonstration of some major pieces of process and handling equipment has been completed. Further effort is planned to establish processing parameters and other equipment-design criteria. Construction of the hot facility is planned as the second phase of the PRE program. In the third phase of the program, "cold" and tracer-level operation will be followed by remote processing of short-cooled, high-burnup, power-reactor fuel. "Hot" operation of the PRE process can develop fuel-cycle-cost information and operating procedures to demonstrate the feasibility of low decontamination processes for irradiated nuclear fuel.

* * *

The work described was performed under AEC Contract AT(11-1)-GEN-8 by members of the PRE Group at Atomics International, especially J. L. Ballif, G. L. Schmidt, D. J. Stoker, H. Bernard, G. Gustovich, D. Janeves, and T. A. Golding. We wish to thank E. E. Motta for his interest and support.

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Fission-Neutron Cross Sections for Threshold Reactions

By ROBERT S. ROCHLIN
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THIS DATA SHEET presents published and unpublished data on fission-spectrum-neutron activation by the (n,p), (n,α) and $(n,2n)$ reactions. We shall refer to these three reactions as threshold reactions, although many of them are exoergic. Although many (n,γ) cross sections have been measured (*1*) for both thermal and fission-spectrum neutrons, data on reactor-neutron activation by the threshold reactions are comparatively scanty.

Cross sections for threshold reactions are needed for calculating activation levels of reactor coolants and components, especially when these reactions produce longer-lived activities then the corresponding (n,γ) reactions. For example, in the case of aluminum the (n,γ) product decays with a 2.3-min half-life, while the (n,α) product has a half-life of 15 hr.

An example of the usefulness of threshold reactions for neutron-activation analysis of materials is the detection of aluminum in silicon, using the $Al^{27}(n,\alpha)Na^{24}$ reaction. The $Al^{27}(n,\gamma)Al^{28}$ reaction cannot be used in this case, because Al^{28} is also produced from silicon by the $Si^{28}(n,p)Al^{28}$ reaction. Na^{24}, on the other hand, cannot be produced from silicon by reactor neutrons.

Threshold reactions are also useful for measuring fast-neutron fluxes in nuclear reactors. By using several elements that have different activation thresholds, information can be obtained about the neutron energy spectrum.

Neutrons produced by fission of uranium-235 have a distribution of energies (*2*) given by

$$N(E)\,dE = (2/\pi e)^{1/2} e^{-E} \sinh (2E)^{1/2}\,dE$$

The cross section for a neutron-induced reaction depends on the energy of the incident neutrons. For fission-spectrum neutrons, an "effective cross section" is defined as (*3*)

$$\sigma_e = P/NF$$

where P is the number of product nuclei formed per unit time, N is the number of target nuclei, and F is the total flux density of fission neutrons of all energies, whether or not they contribute to the reaction.

Because of the steep slope of the fission spectrum above 2 Mev, the effect of moderated neutrons on the spectrum can usually be neglected in the energy range above 2 Mev.

Neutron energy thresholds for endoergic reactions are given by $E_T = -Q(A+1)/A$, where A is the atomic weight of the target nuclide, and the Q of the reaction can be calculated from isotopic-mass tables (*4*). Threshold energies are listed in the table. Negative "thresholds" indicate exoergic reactions, for which even thermal neutrons may have a cross section greater than zero. However, even for exoergic reactions, the potential barrier against particle emission (*3*) usually causes the cross sections to be small for thermal neutrons.

Inthoff (*5*) has prepared a nomogram for fission-neutron (n,p) and (n,α) cross sections, based upon the theory described by Hughes (*3*). This theory gives rough agreement with many experimental values, but in some cases (e.g., Ti, Cs, Tl) there are disagreements by factors of 100 or more (*6–8*).

Experimental Techniques

In the present work, samples of Al, Cd, Co, Cu, Fe, Ge, Ni, Sc and Zn were irradiated in the Brookhaven National Laboratory graphite reactor. The fission-neutron-flux calibration was based upon an assumed effective cross section of 0.60 mb for $Al^{27}(n,\alpha)Na^{24}$.

To reduce interference from impurities, Matthey "Specpure" oxide samples were used. To check on interference from activation of impurities by thermal neutrons, samples of each element were irradiated with and without a tight wrapping of cadmium. Since the thermal-neutron flux inside the cadmium wrapping was negligible, the ratio of measured activities of samples with and without cadmium would depart from unity if thermal-neutron activation were appreciable. In the present work, calculation of this ratio revealed no activities due to thermal-neutron activation of impurities in any of the samples.

Chemical separations were made to facilitate measurement of weak activities, which would otherwise have been masked by stronger ones.

To obtain unique identification of each reaction product, both gamma-ray energies and half-lives were measured. Values of photons/disintegration for each observed gamma peak were taken from references *9*, *10* or *11*. The relative counting efficiency of the NaI scintillation spectrometer as a function of gamma-ray energy was obtained by comparing observed peaks of Mn^{56} and Br^{82} gamma rays with their known relative intensities (*9*).

* * *

I want to thank S. I. Friedman for his diligent assistance in operating the spectrometer and calculating data, Miss B. A. Thompson and A. Eldridge for making the chemical separations, and W. W. Schultz for continual encouragement and support.

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Effective Cross Sections for Fission-Spectrum Neutrons

Reaction	*Half-life*	E_T *(Mev)*	σ_a *(mb)*	*Ref.*
$Al^{27}(n,p)Mg^{27}$	10.2m	1.90	3.43	*12*
			2.8	*13*
$Al^{27}(n,\alpha)Na^{24}$	15h	3.27	0.60	*12*
			0.6	*13*
			0.44	*7*
$Ba^{132}(n,p)Cs^{132}$	6.2d	~0.	5.3	*14*
$Ba^{136}(n,p)Cs^{136}$	13d	2.06	0.0015	*14*
$Be^{9}(n,\alpha)He^{6}$	0.82s	0.71	10.	*13*
$B^{11}(n,\alpha)Li^{8}$	0.84s	7.24	0.085	*13*
$Cd^{110}(n,p)Ag^{110}$	270d	2.12	~0.1	*8*
$Cl^{35}(n,p)S^{35}$	87d	−0.62	16.	*13*
$Cl^{35}(n,\alpha)P^{32}$	14.3d	−0.92	3.0	*13*
			4.1	*7*
$Cl^{37}(n,p)S^{37}$	5.0m	3.6	0.24	*13*
$Co^{59}(n,p)Fe^{59}$	45d	0.79	0.25	*15*
			~0.3	*8*
			5.7	*6*
$Co^{59}(n,\alpha)Mn^{56}$	2.58h	−0.44	0.14	*7*
$Cs^{133}(n,\alpha)I^{130}$	12.6h	−4.22	2.4×10^{-4}	*7*
			$5. \times 10^{-4}$	*6*
$Cu^{63}(n,\alpha)Co^{60}$	5.4y	−1.59	0.72	*8*
$F^{19}(n,p)O^{19}$	30s	4.21	0.5	*13*
			0.99	*7*
$F^{19}(n,\alpha)N^{16}$	7.5s	1.57	4.5	*13*
			4.5	*7*
$Fe^{54}(n,p)Mn^{54}$	291d	−0.16	11.	*16*
			15.	*15*
			23.	*6*
			56.	*8*
$Fe^{54}(n,\alpha)Cr^{51}$	27.8d	−0.862	0.37	*6*
$Fe^{56}(n,p)Mn^{56}$	2.58h	2.94	0.44	*6*
$Ge^{70}(n,2n)Ge^{69}$	39.6h	11.9	1.5	*8*
$Ge^{72}(n,p)Ga^{72}$	14.1h	3.27	<0.01	*8*
$Ge^{72}(n,\alpha)Zn^{69}$	13.8h	−1.12	<1.	*8*
$Mg^{24}(n,p)Na^{24}$	15h	4.95	1.29	*12*
			1.0	*13*
$Mg^{25}(n,p)Na^{25}$	62s	3.1	2.0	*13*
$Mn^{55}(n,2n)Mn^{54}$	291d	10.33	0.05 (?)	*15*
$Mo^{92}(n,p)Nb^{92}$	10d	−0.416	1.3	*6*
$Mo^{92}(n,\alpha)Zr^{89}$	79h	−3.00	0.017	*6*
$Mo^{95}(n,p)Nb^{95}$	35d	0.150	<0.1	*6*
$Na^{23}(n,p)Ne^{23}$	40s	3.76	0.7	*13*
			1.0	*7*
$Na^{23}(n,2n)Na^{22}$	2.6y	12.98	0.006	*13*
$Na^{23}(n,\alpha)F^{20}$	11.6s	4.07	0.4	*13*
			0.47	*7*
$Nb^{93}(n,\alpha)Y^{90}$	64.0h	−4.87	0.024	*7*

Reaction	*Half-life*	E_T *(Mev)*	σ_a *(mb)*	*Ref.*
$Ni^{58}(n,p)Co^{58}$	72d	−0.64	40.	*15*
			45.	*17*
			45.	*18*
			140.	*8*
			225.	*14*
$Ni^{58}(n,p)Co^{58m}$	9.0h	−0.64	13.	*6*
$Ni^{58}(n,\alpha)Fe^{55}$	2.9y	−3.06	0.17	*15*
$Ni^{58}(n,2n)Ni^{57}$	36h	12.0	0.0012	*15*
$Ni^{60}(n,p)Co^{60}$	5.4y	2.07	<4.5	*14*
			5.	*6*
			<2.	*8*
			0.56	*15*
$Ni^{62}(n,\alpha)Fe^{59}$	45d	0.884	0.013	*15*
			0.025	*6*
			0.14	*8*
$O^{16}(n,p)N^{16}$	7.5s	10.22	0.014	*13*
			0.019	*19*
			0.0185	*20*
$O^{17}(n,p)N^{17}$	4.14s	8.47	0.0052	*19*
			0.0093	*20*
$P^{31}(n,p)Si^{31}$	170m	0.72	31.2	*12*
			19.	*13*
$P^{31}(n,\alpha)Al^{28}$	2.4m	2.02	1.43	*13*
			0.75	*7*
$S^{32}(n,p)P^{32}$	14.3d	0.95	154.	*16*
			60.3	*12*
			30.	*13*
			21.	*7*
$S^{34}(n,\alpha)Si^{31}$	170m	1.24	3.0	*13*
			1.2	*7*
$Sc^{45}(n,\alpha)K^{42}$	12.5h	0.61	<5.	*8*
$Si^{28}(n,p)Al^{28}$	2.4m	4.01	4.	*13*
$Si^{29}(n,p)Al^{29}$	6.7m	3.1	2.7	*13*
$Ta^{181}(n,\alpha)Lu^{178}$	22m	?	8.5×10^{-5}	*7*
$Th^{232}(n,2n)Th^{231}$	25.6h	6.3	12.4	*21*
$Ti^{46}(n,p)Sc^{46}$	85d	1.61	4.10	*6*
$Ti^{47}(n,p)Sc^{47}$	3.4d	−0.096	0.21	*6*
$Ti^{48}(n,p)Sc^{48}$	44h	3.28	0.077	*6*
$Ti^{48}(n,\alpha)Ca^{45}$	164d	2.02	0.0055	*6*
$Ti^{50}(n,\alpha)Ca^{47}$	4.7d	3.58	0.0002	*6*
$Tl^{203}(n,p)Hg^{203}$	48d	−0.297	0.002	*6*
$U^{238}(n,2n)U^{237}$	6.6d	6.09	4.7	*15*
$V^{51}(n,\alpha)Sc^{48}$	44h	2.14	0.08	*13*
			0.0099	*7*
$Zn^{64}(n,p)Cu^{64}$	12.8h	−0.22	35.	*8*
			22.	*6*
$Zn^{67}(n,p)Cu^{67}$	59h	−0.214	0.27	*6*
$Zn^{68}(n,\alpha)Ni^{65}$	2.56h	−0.93	0.020	*7*

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Environmental Surveys for Nuclear Facilities

To be aware of the effect a nuclear facility may have on the radioactivity level of its environment, a system must be set up to monitor land, air and water. The author lists instrumentation and personnel needed and estimates costs

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A LARGE NUCLEAR INDUSTRY will carry with it the hazard of release of radioactive material. This will include laboratory and processing wastes and activities induced in reactor effluents, as well as fission products. To maintain the radioactivity level of the environment at a tolerable level, a program will be needed for continuously monitoring the area surrounding a nuclear facility, i.e., an environmental survey.

An environmental survey consists of two phases—radioactivity measurements before and during operation of the facility. Several purposes are served by it:

1. To determine if the radioactivity level of the environment is being raised by the facility.
2. To detect the concentration of any released activity.
3. To serve as a final check on control procedures.
4. To provide tangible evidence in the event of litigation.
5. To demonstrate to the public the precautions taken for its safety.

The most efficient survey will yield a maximum amount of information from a minimum number of measurements. On the other hand, it is desirable to have overlapping measurements for checking purposes. The optimum survey will achieve a balance between these two considerations.

Survey for Reactor

To limit the scope of this article, an environmental survey for a high-power reactor installation is used as an example. It should be recognized that geological and climatological conditions at the location of a given reactor and operating characteristics of the reactor (*1, 2*) may modify the survey outlined here.

Preoperational survey. The minimum duration of this survey is one year prior to start up so that all seasonal fluctuations can be measured. An optimum period is probably 18 months, including all the best weather possible, e.g., two summer seasons in the colder climates.

Operational survey. By start-up time, surveying experience will have indicated the most active spots in the area, i.e., the particular vegetation, animals, water locations, etc., most likely to concentrate any released activity.

Depending on the particular type of reactor used, it may be desirable to make occasional specific determinations of the isotopes most likely to escape.

In general, the difference between the two surveys should be only temporal. After several years of operating experience, it may be found that the magnitude of the survey can be safely curtailed.

The various ecological cycles must be considered when determining the proper media to be sampled. The cycles are considered here under the headings "Water," "Air" and "Land."

Water

A complete evaluation of radioactivity in natural waters will include analyses of both ground and surface waters.

Ground water. Ground-water samples can be taken from wells or springs already present. Wells dug especially for this purpose have the advantage of being appropriately positioned relative to anticipated sources of contamination.

Surface water. When sampling fixed bodies of water, such as lakes and ponds, one must know the method of "turnover," i.e., how and where the water enters and leaves. This implies at least a limited knowledge of the hydrology in the area.

Moving bodies of water (hereafter referred to as streams), especially those involved with the facility effluent, are of particular importance in the environmental survey.† Inherent with most streams is the capacity for self-purification. A fresh stream can render harmless most nonradioactive industrial wastes in a few hours. The stream water is purified by a transfer of radioactivity to the stream bottom, fish and algae. However, purification of the stream environment as a whole must ultimately be by radioactive decay.

A radioactive stream survey should include samples from three different media: water, biological life and bottom material. From these measurements, information can be obtained relating to natural radioactivity content, fallout and degree and types of concentration to be expected.

Water samples. Water sampling can be accomplished by two methods—continuous or spot. Whether one method or both are used will depend on the particular survey.

Continued on page 58

* PRESENT ADDRESS: Bethlehem Steel Co., Bethlehem, Pa

† Reference *8* gives a comprehensive treatment of stream parameters relative to radioactive waste disposal.

Are Surveys Necessary?

NO

Pelletier groups power reactors, nuclear laboratories, research centers and chemical processing centers in the general classification of large-scale nuclear installations. Actually, the potential hazard to the neighboring community is quite different in several respects, and, in particular, a power reactor differs from all the others. The author, however, chooses this one to discuss particularly.

In the case of a power reactor, there is always a risk that there will be a runaway incident, such as the Chalk River and Windscale accidents, although the probability is extremely low because of the multiplicity of safeguards being built into power reactors. On the other hand, power reactors now being designed and built appear to offer little, if any, risk of the slow escape of radioactive materials. If such an escape were to occur, the operators should have definite and quantitative knowledge of it.

Extensive measurements of environmental radiation and radioactive content of soils and plants are now being made throughout the country. It is becoming clear that there is very little variation in background that cannot be accounted for by cosmic radiation (altitude), presence of radioactive minerals (rock outcroppings and certain building materials) and fallout from weapons tests. The frequently mentioned diurnal and seasonal variation of background radiation has not been observed by any acceptable dosimetric technique. Any additional fallout or contamination as the result of a reactor failure could be easily distinguished from the other known sources without a special preoperational survey.

When the Brookhaven National Laboratory was first established, a chain of off-site continuous monitoring stations were operated. With time, all but two were discontinued for reasons of economics, since it was found that none of them showed significant readings.

The establishment of off-site power-reactor monitoring stations where there is no justifiable need for them might be psychologically bad in that the community would be continually reminded of the potential hazard. If the reactor were to run away, the monitoring stations would offer little data that could not be obtained more economically and more completely by field survey techniques. Since all current power-reactor designs provide for a completely enclosed reactor in a completely enclosed building, with all possible modes of exit of radioactive materials carefully monitored, any leakage could be detected immediately.

In the event of a claim of neighborhood contamination (whether true or false), it would be a relatively simple matter, using modern radiometric techniques, to determine the character and age of any contaminant to relate it to any particular source.

It should be made clear that the above remarks refer to power reactors. In the case of fuel-element chemical-separation plants or certain types of laboratory or test facilities, some of the statements may not apply. Such plants, if operated without the proper safeguards, could cause a gradual increase in the local environmental radiation background and appropriate precautions should be taken. It is very important, however, for us not to establish the precedent of considering costly preoperational surveys an essential part of the already heavily burdened economics of producing atomic power.

It has been proposed recently that aircraft be utilized to establish a radiation background pattern in any area in which a nuclear installation is to be constructed. In fact, a few such surveys have been conducted already. Such a preoperational survey has the advantage that it could be done over a wide area at relatively small cost and, in the event of an accident, could be repeated to determine quickly whether the original radiation background pattern had been disturbed. It is believed that this type of survey would not attract as much attention as the work of water, plant, soil and air sampling teams operating over a period of many months.

It should be made clear that the opinion of the author in these matters does not necessarily represent the official position of the Atomic Energy Commission, particularly with respect to the psychological effect on the community of extensive preoperational surveys. There is an honest difference of opinion in some quarters. The Commission, at present, does not require such a survey as a licensing condition, but leaves this determination up to the applicant.

—Hanson Blatz
New York Operations Office
U. S. Atomic Energy Commission
New York, N. Y.

YES

Environmental surveys, properly conducted, will yield information that is valuable for safe and efficient operations.

The Atomic Energy Commission requires reactor operators to show that the radioactivity tolerance levels in air and water are not exceeded. It is not felt that these measurements alone completely fulfill present needs of reactor operators. Operational, public relations, insurance and legal requirements make it necessary that more complete data should be available.

The type of data that would be useful would indicate a gradual buildup of activity. This, of course, indicates faulty application of the measures being employed to prevent this occurrence. However, if the program is not adequate to detect activity buildup, then an emergency shutdown of operations may result from the discovery that tolerance levels have been reached or exceeded.

The gradual buildup of radioactivity in an area surrounding a reactor site becomes an ingestion problem long before it is an external radiation hazard and thus becomes a public relations and legal problem. Therefore, in addition to the analysis of air and water, the various components of the food chain should be examined.

Inasmuch as fallout will deposit the same material that is to be expected from reactors, an adequate program should be completed prior to reactor startup. The analysis program should be able to distinguish between the two sources of radioactivity, i.e., fallout and reactor operations.

It is advantageous for at least a portion of the surveys and analyses to be performed by an independent group for legal reasons.

—Abraham Edelmann
Nuclear Science and Engineering Corp.
Pittsburgh, Pennsylvania

One type of continuous sampler is used above and below the Shippingport nuclear power station in the Ohio River (*10*). It was designed by the Bettis Industrial Hygiene Department of the Westinghouse Atomic Power Division. It collects 3–4 gal/week in a container that is emptied weekly. Another, originally designed for ordinary industrial wastes (*10*), is used below a uranium-processing plant. It operates by diverting water into a 2-gal polyethylene container that is emptied every 24 hours.

The location of continuous samplers is of prime importance. Placing the sampler too close to the outfall will not allow for sufficient dilution and contamination of the sampler may become a nuisance. Also, the stream flow relative to the plant effluent, as well as a history of the stream-flow magnitudes, should be known.

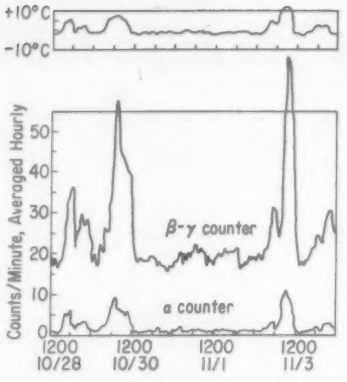
A spot sample gives only an instantaneous measure of the water concentration at a particular point. However, a number of well chosen sampling locations can give a good picture of radioactivity in the whole body of water at any given time.

Biological life. The propensity of certain water biota (algae, fungi and plankton) to concentrate radioisotopes is well known (*4, 13, 18, 22*). The mechanisms of concentration seem to be absorption and/or adsorption (*10, 13*). Among other organisms, the cadis fly larva concentrates P^{32} by a factor of 350,000 (*13*).

Fish also concentrate radioisotopes (*4, 10, 17, 19*). Since specific elements are utilized in different parts of the body, the amount of activity in a few grams of bone, scale and flesh should be analyzed separately (*17, 19*). As one would expect, strontium is preferentially absorbed in the bone and scale and cesium in the muscle.

The capacity of water biota for radioisotope concentration depends on many variables (*10*). In general, greater amounts of activity will be found in living organisms during the summer months when metabolic activity is highest.

Bottom material. Stream bottom in the form of mud and silt is another medium to be sampled. An increase in beta-gamma activity from 20 dpm/gm to 50 dpm/gm from 1950 to 1954 has been attributed to fallout (*11*). Obviously, the wider portions of the stream, where the velocity is lower and more sedimentation takes place, are the most suitable sampling spots.



DATA collected by dust monitor at Brookhaven show close correlation of temperature inversion and activity

Although the biota and mud samples are of the spot type, they give cumulative information, i.e., information relating to past deposition in the stream.

Air

The continuous measurement of radioactive particulate matter in the atmosphere gives valuable information concerning natural radioactivity as well as fallout. In addition to actual radiation-monitoring data, meteorological data (wind speed and direction, temperature and precipitation amounts) will also have to be collected (*3, 7*).

At Brookhaven National Laboratory, particulates are continuously collected on a filter-paper tape, which is then passed by alpha and beta-gamma detectors (*7*). Typical data are shown in the illustration. The curves show how well these data relate to natural inversion conditions—note how both the alpha and beta-gamma curves rise simultaneously.

Such a continuous dust monitor cannot measure foreign particulate matter in the range of the MPC's stated for large populations (*3*). As Whipple has pointed out (*3*), even by monitoring on an integrating basis, such low levels can be counted only with the greatest of difficulty. However, by using a large-area filter paper and collecting particulates over a 24-hr period, followed by a long period in which the natural short-lived isotopes decay, an estimate of the long-lived activity in the air can be made. One such unit should suffice. ANL utilizes such a method and obtains natural long-lived activity estimates of about 0.03 $\mu\mu c/m^3$ alpha and $1 \mu\mu c/m^3$ beta-gamma (*9c*).

External radiation arises from three sources: (1) cosmic radiation, (2) gamma-emitting isotopes in the soil and (3) radon and thoron and their daughter products in the air. Two G-M detectors, one shielded and one thin window, will measure and to some extent distinguish between the three.

Dose measurements. Dose has been measured with high-sensitivity film and integrating-type ionization chambers (*8*). The sensitivity of these two methods is questionable. Their main value, and for that matter the value of measuring dose at all, would be during an accident where large amounts of radioactivity might escape to the environment. BNL uses a vibrating-capacitor electrometer to measure dose from the argon-41 induced in its air coolant. For water or sodium-cooled reactors, this type of measurement is not necessary.

Land

Radioactivity on land will be located in the soil, vegetation and animals.

The sources of radioactivity in the soil are (1) the natural elements (Ra, Th, U and K^{40}), (2) surface deposition of fallout and (3) radionuclides deposited in the soil by rain and subsurface water. A few grams of soil either from the surface or subsurface are adequate to perform gross alpha and beta-gamma analyses.

Activity (other than natural) can reach vegetation by two routes: direct deposition on the leaves or uptake through the roots. Activity is predominantly concentrated in the leaves and stems; the least is found in fruiting organs or seeds (*24*). The condition of the soil plays an important role in determining the concentration due to root uptake. Certain varieties of plants concentrate Sr^{90} to a greater degree in acidic soils than in alkaline soils (*25*). Here again a few grams of vegetation will give reasonably accurate results with conventional counting equipment.

The analysis of a few grams of bone, flesh and possibly thyroid will give an average level of radioactivity in any animal. Young animals, where the rate of biological activity is highest, should yield the highest activities.

Laboratory Facilities

For sample analysis, equipment will be needed for the following operations: separation, including ashing, drying, evaporating, dissolving and filtering, and counting.

Equipment to perform the separation will cost about $4,000. This includes exhaust hood, analytical balance, chemicals and chemical apparatus, as well as an oven, infrared lamps, hot plate and filtering apparatus.

A gas-flow proportional alpha counter is commercially available. It has a low background and high efficiency (50%), which are both essential. With proper voltage adjustment, this counter can also be used to count betas and gammas. Two such counters can handle 150 or more samples per month. The cost of counting equipment should not exceed $2,500.

Then, a rough cost estimate for a laboratory facility including building, office furnishings and equipment will be about $18,000. Of this, $10,000 is assumed for building construction.

Monitoring Stations

A minimum of four permanent monitoring shacks, one at each major point on the compass, is needed. A fifth station is also desirable to be moved to any site desired, or to be located permanently to complement the shack in the direction of the prevailing wind. Proximity of the sampling locations will vary with local conditions.

A wide range of commercial equipment is available with widely varying prices. Typical prices are $3,500 for a continuous dust-monitor recorder; $3,000 for 2 G-M detectors, scalers, power supplies and printout; and $300 for an automatic charger for one detector in case of power failure. Thus, capital equipment for five shacks plus the laboratory facility will be roughly $55,500.

Records

An important consideration when planning the survey is the method of keeping records. Since the *original* records will be the only valid evidence in legal cases, they will have to be stored for long periods of time. The tabulations of these raw data will also have to be stored. Therefore, the most concise method possible is desirable.

There is little that can be done to reduce the volume of records showing results from laboratory analyses. However the bulk of these records should be small when compared to the data from the G-M and particulate monitors.

To record the data from sixteen monitoring stations at BNL, the counts from the dust monitor and G-M tubes were photographed at a central panel every six minutes (7). This method is attractive for very large numbers of readings.

Strip charts fed from a counting-rate meter are also used to record data. The resultant chart will not be as accurate as numbers obtained by an integrating instrument. Printing registers set to read out the number of counts at a specified time (say every 10–20 minutes), the data and time will give an accurate account of background counting rates.

With five stations producing five such rolls of data weekly, at the end of six years, 300 cubic feet of storage capacity will be needed to keep these original records.

Personnel Requirements

Duties to be performed by personnel are instrument installation and maintenance, sample collecting, laboratory analyses, data handling and interpretation and general survey supervising.

If one individual is available full-time to supervise, interpret data and install and maintain equipment, then a minimum of four permanently employed individuals is needed—one laboratory technician to perform routine analyses, one person for data handling and one field man.

* * *

I would like to thank the many instrument manufacturers for their aid in estimating instrument costs. I especially would like to thank John Handloser, BNL, and G. Hoyt Whipple, the University of Michigan, for their criticisms and suggestions. However, all the information presented is my responsibility.

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Making Fission Counters for Neutron Monitoring

Careful consideration of geometry, thickness of fissionable coating, pulse differentiation and discriminator biasing leads to counters with high sensitivity and low background

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FISSION COUNTERS for reactor monitoring are generally required to measure a flux range of about 6 decades. In starting up with fresh fuel the range may be as much as 12 decades. After operation it takes more than a month for the flux to drop by 10^6.

The usual method for covering 6 decades is with an ionization chamber. Such a chamber is almost black to neutrons, and a flux depression results. The most serious disadvantage, however, is sensitivity to radiation other than neutrons. For example, in the Chalk River T.Q.U. chamber (*1*) 1 r of gamma rays produces the same flux as 200 n/cm²/sec.

The desirable characteristics of a fission counter for reactor control can be summarized as follows:

1. Robust construction
2. Good discrimination between neutrons and gammas
3. Counting rate independent of anode voltage and discriminator bias
4. Acceptable life at maximum counting rate
5. Small dimensions; materials with small capture cross sections and short-lived induced activities
6. Sensitivity readily controllable during manufacture
7. Large counting-rate range ($\sim 10^6$)

We have developed two types of fission counters for reactor monitoring. Both use neutron-induced fission in U^{235}. A cylindrical one is for isotropic fluxes of 10–10^6 n/cm²/sec. The other is for monitoring neutron beams of 5×10^5–5×10^9 n/sec and is of parallel-plate form.

DESIGN CONSIDERATIONS

The designer's principal problems are those of separating fission pulses from alpha-particle counts. The ratio of the two is better if U^{235} is used than it would be with other fissionable nuclides. Mechanisms of electrostatic pulse formation show that the designer should coat only the cathode with fissionable material, select the initial portion of the particle tracks, and choose an optimum thickness for the coating.

Fission-Alpha Separation

Since no known gaseous compound of fissionable materials is suitable for electron collection devices (*2, 3*), the fissionable material is introduced as a deposit. Thus only one fragment from each fission is available to ionize the counter gas.

U^{235} is the most suitable of the common fissionable nuclides, U^{233}, U^{235} and Pu^{239}. The fission cross sections are comparable, but the alpha activity of U^{235} is least by a factor of 10^4. This means that much more U^{235} can be used before alpha activity becomes troublesome. However, uranium enriched in U^{235} usually contains U^{234}, and irradiation produces U^{236} as well. U^{234}, with 2.5×10^5-yr half-life, makes the major contribution to the activity. Thus the number of alpha particles from enriched uranium is usually 2.4×10^3 particles/sec/mg of U^{235}, which is to be compared with 3.5×10^5 for U^{233} and 2.3×10^6 for Pu^{239}.

Track length. In the fission of U^{235}, the most probable energies available for ionization are 93 Mev for the light fragment and 59 Mev for the heavy one (*4*). The maximum alpha-particle energy is 4.76 Mev from U^{234}. Thus discrimination between the mean of the lower-energy fission fragments and single alpha particles is 12.4:1. This assumes that all ions are collected from each particle and the voltage pulse is proportional to this ionization.

It is possible to improve this discrimination by selecting only the first section of each track (*5*). The energy loss of fission fragments along their range has been measured in several gases (*6*). Average loss of the median light fragment in the first few millimeters is ~5.8 Mev/mm. The alpha particle loses energy at 0.09 Mev/mm. Thus for the first 4 mm of each track, discrimination between fission fragment and alpha particle is ~64:1.

This discrimination can be achieved only by making all track lengths equal. This is not possible in a sensitive counter with a large uncollimated source. The electrode geometry of such counters is usually parallel plate or an approximation to it. The best discrimination between median heavy fragment and average alpha particle—about 20:1—is achieved when effective electrode spacing is a little less than the heavy-fragment range.

Alpha pile-up. Interference with fission counting comes mainly from alpha-pulse pile-up of fairly high multiplicity. Superposition of several pulses within the amplifier response time results in a pulse large enough to simulate that of a fission fragment.

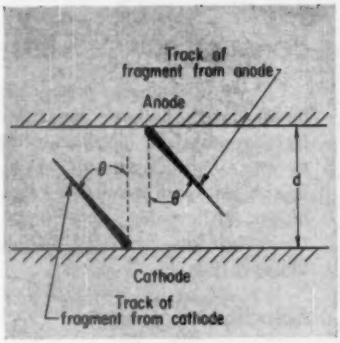


FIG. 1. Consideration of identical fission fragments emitted from cathode and anode shows that best fission-alpha discrimination requires coating only cathode with fissionable material

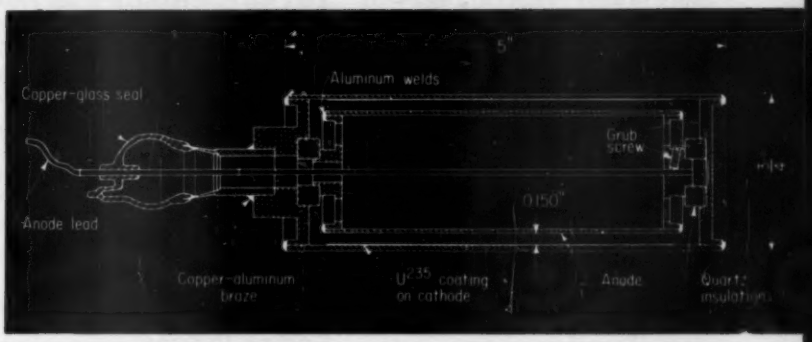


FIG. 2. Type 1 counter has concentric cylindrical anode and cathode. Anode lead enters by way of copper-glass seal, and especially developed copper-aluminum braze seals copper to aluminum end plate

A rough estimate of the pile-up effect can be made by neglecting self-absorption and assuming that all ions are collected. If each alpha pulse is replaced by an equivalent rectangular pulse (7), the overlap probability is given by the Poisson formula. The probability of a second pulse occurring in time t after the first is $P_1 = nte^{-nt}$. Here n is the mean pulse rate. Similarly the probability of x pulses occurring is given by

$$P_x = \frac{(nt)^x}{x!} e^{-nt}$$

Thus, if t is measured from the start of any pulse, P_1 is the probability per pulse of a second pulse occurring within the interval, and this will happen nP_1 times per second. In a counter containing 60 mg of U^{235} in 64 mg of uranium, the expected alpha counting rate is 7×10^4 cps. If this counter is used in conjunction with an amplifier of 0.2-μsec rise and fall time constants and counter pulse rise time of 0.7 μsec, an equivalent rectangular pulse length is 0.84 μsec (8). There is a significant probability of up to five pulses overlapping. The probability per pulse of five overlapping is 4×10^{-7}. Thus the discrimination between median heavy-fission-fragment pulses and alpha pile-ups is about 4:1. Alternatively, an alpha-pile-up counting rate of 2 ppm can be expected at a pulse amplitude corresponding to ¼ of that of the median heavy fission fragment.

Special gas fillings. Alpha pile-up can be reduced and response times can be shortened by using special gas fillings. For high counting rates it is desirable to reduce collection time below that obtainable with pure argon (~0.7 μsec). Methane or argon-methane mixtures can be used (9, 10). No complete investigation has been made, but we have tested counters filled with 90% argon and 10% methane and found them to operate satisfactorily. Measured collection time was 0.06 μsec at an anode potential of 300 volts and a pressure of 3 atm—in reasonable agreement with published data.

With pure methane and a higher potential the collection time should be even shorter. In principle it is thus possible to achieve a dead time of perhaps 0.030 μsec, which would permit counting rates approaching 10^7 pps. In practice, however, performance obtainable from conventional electronic equipment would restrict possible counting rates to ~10^6 pps.

Pulse Formation

A drifting ion causes a current that flows until the ion reaches an electrode. The current is integrated by the self-capacitance of the counter to give a voltage pulse. In the time for an electron to cross the chamber the contribution from a positive ion is small since positive-ion drift velocity is ~1/1,000 of the electron velocity. Thus electrons produce a fast output pulse, the size depending essentially on the average distance moved by the electrons before collection (11). Ionization near the anode gives small electronic pulses so a fissionable coating on the anode is undesirable.

Figure 1 compares anode and cathode coatings. Identical fission fragments, one from the anode and one from the cathode, make angles θ with the normal to the electrodes. It is assumed that specific ionization of a fission fragment decreases linearly along the track and that track length is equal to electrode spacing d. T_d is the drift time for an electron to cross the counter from cathode to anode. The following is the voltage pulse for the fragment from the anode as a function of time t and maximum possible pulse height V ($= Q/C$)

$$v = V\left[\frac{t}{T_d} - \left(\frac{t}{T_d}\right)^2 \frac{1}{\cos\theta} + \left(\frac{t}{T_d}\right)^3 \frac{1}{3\cos^2\theta}\right] \quad (1)$$

$$0 \le t \le T_d \cos\theta$$

The voltage pulse for the fragment from the cathode is

$$v = V\left(\frac{t}{T_d}\right)$$

$$0 \le t \le T_d(1 - \cos\theta)$$

This applies up to the time of the collection of the first electrons at the anode, and after that

$$v = V\left\{\frac{t}{T_d} - \frac{\left[\frac{t}{T_d} - (1 - \cos\theta)\right]^3}{3\cos^2\theta}\right\} \quad (2)$$

$$T_d(1 - \cos\theta) \le t \le T_d$$

If the full height of the voltage pulse is used, Eq. 1 for $t = T_d \cos\theta$ shows that fission fragments emitted isotropically from the anode give rise to a rectangular voltage-pulse distribution

from 0 to $0.33V$, while Eq. 2 for $t = T_d$ shows that fragments emitted isotropically from the cathode give rise to a rectangular voltage-pulse distribution from $0.67V$ to V. The latter distribution is clearly more satisfactory.

For both anode and cathode coatings, the initial slope of the voltage pulse is V/T_d, independent of θ. Thus sharp differentiation of the voltage produces a pulse dependent only on the number of ions formed by the fragment and independent of the position and orientation of the track in the counter (*12*).

Methods of operation. These considerations lead to two methods of operating a fission counter: (a) amplifier output proportional to counter voltage pulse; (b) output pulse proportional to ion-chamber-current pulse, the derivative of the voltage pulse.

The derivative method is in principle capable of giving a better pulse-height distribution. However, there is a substantial spread in fission-fragment energies. If the instrumental dispersion of pulses is less than this natural spread, the resultant distribution will not be much wider than the natural distribution. For example, if pulses of height V are modified so that they are uniformly distributed between $0.67V$ and V and this process is applied to pulses in a Gaussian distribution of 50% width at half maximum, the width of the resultant distribution is only about 58%. Fission fragments are distributed over approximately a 2-to-1 energy range. Thus fast differentiation of the voltage pulses from a cathode-coated fission counter would not be expected to improve greatly the pulse-amplitude distribution.

It could be used to improve the performance of a counter with a fissionable coating on the anode as well as the cathode. But for oblique tracks from the anode, the rate of rise of voltage decreases very quickly, and to obtain a reasonable pulse spectrum it would be necessary to differentiate very sharply.

Coating Thickness

An oblique fission fragment can expend a considerable portion of its energy in the deposit before entering the gas. If it does, it will give a pulse comparable to that of a low-trajectory alpha particle coming from the surface of the deposit. The estimated mean range of a fission fragment in U_3O_8 is 10 mg/cm² (*13*). Calculation shows that if half of this range is set as an upper limit through which a fission fragment can penetrate and still give a pulse above the detector bias, ~95% of the fissions taking place in a 0.5-mg/cm² deposit are detectable. The correction for cylindrical geometry is 0.05% for a 2-cm cathode radius and increases to 0.2% for a cathode radius of 0.5 cm (*14*). As the deposit thickness increases, a larger fraction of the fission pulses lie below the bias level, and the separation of fission and alpha pulses is more poorly defined.

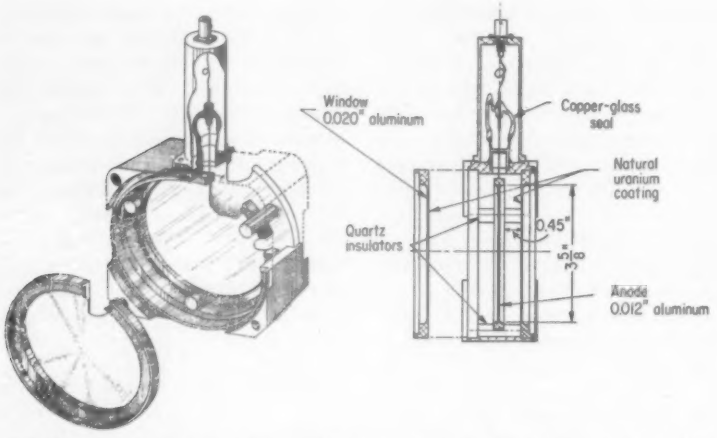


FIG. 3. Type 2 counter is plane-parallel type with natural-uranium coating on thin outside windows. Design reduces neutron-beam attenuation to a minimum. 0.45 dimension should extend to anode plane

CONSTRUCTION DETAILS

In view of their use in large neutron fluxes, fission chambers must be made from appropriate materials. Making a good-quality uranium deposit of known thickness requires special techniques. Allowance must be made in the design for evacuating, baking and filling.

Selection of Materials

It is important to use mainly constructional materials with small neutron cross sections and to restrict the use of materials that either become strongly radioactive with long half-lives or suffer deterioration under neutron or gamma irradiation. Thus we use aluminum (Alcan 1S H14) in the construction except for insulator assemblies. The internal insulators are of quartz (fused silica), and the insulating seal is copper-glass-tungsten.

The average macroscopic cross section for our Type 1 counter under total neutron irradiation is approximately 0.05 cm^{-1}. This high value, being due mainly to the boron in the 7740 Pyrex anode seal, can be reduced to 0.007 cm^{-1} by using soda glass instead of Pyrex for the seal.

Deposition of Uranium

As a first step in depositing the fissionable coating the cathode surface is cleaned by a chemical stripping process like one used in preparing aluminum for nickel plating (*15*).* The uranium is deposited by electrolysis as oxide from an electrolyte of uranyl nitrate dissolved in a 0.2-*M* solution of ammonium oxalate. The *p*H of the solution is adjusted to 8 by adding ammonia.

To control thickness, complete deposition of the uranium in solution is desirable. If the electrolytic method is used for a deposit thickness below about 0.2 mg/cm², aluminum appears in the electrolyte during electrolysis. Presumably this is due to the low concentration of uranyl nitrate. A nonadherent deposit results. However, if the required thickness is greater than 0.2 mg/cm², no aluminum appears, and the uranium is deposited practically quantitatively in a firmly adherent

* 1. Subject to standard vapor degrease. 2. Pickle for 30 sec in a 1:1 aqueous HCl solution at 60° C. 3. Rinse in hot water. 4. Immerse for 30 sec in aqueous solution of 3 parts 38% HNO_3 and 1 part HF. 5. Rinse in hot water.

layer. With a current density of 0.03 amp/cm² and an electrolyte temperature of 76 ± 1° C, 40 min is enough to deposit thicknesses of up to 1.5 mg/cm². Convection currents provide sufficient agitation of the electrolyte to give a uniform coating. The amount of uranium left in the electrolyte is determined by alpha-particle counting. Deposit thickness is calculated from the amount of U^{235} originally in the electrolyte and the amount remaining after electrolysis. The deposit is uniformly brown or black depending on thickness.

For thicknesses less than 0.2 mg/cm², uranium is mixed in a cellulose lacquer and applied by painting and firing in a manner like one that has been described previously (*16*).

Type 1 Counter

In the counter of Fig. 2 anode and cathode are concentric aluminum cylinders. The cathode forms the main envelope and the anode is positioned, supported and insulated by quartz rings located in the end plates. The anode lead is brought out through a copper-to-glass seal. The copper-aluminum joint is a special braze (*see appendix*).

To assemble the counter, the copper-glass seal is brazed into its end plate; the anode lead is passed through an insulator and the anode; the grub screw is tightened so that anode and end plate are held firmly together. This subassembly is then lowered into a cathode in which an end plate has been argon-arc-welded until the projection in the anode is felt to engage in the hole in the quartz insulator. Both pieces are then held tightly together while the anode-seal end plate is welded to the cathode.

Type 2 Counter

The Type 2 counter is a plane-parallel-plate type, shown in Fig. 3. The design is based on results of experiments with the Type 1 counter and gives minimum attenuation to a neutron beam.

The body is machined from aluminum rod, and the end plates from aluminum sheet. After coating, the end plates are argon-arc-welded to the body. For rigidity the thin anode plate is riveted between two rings that fit into slots in three quartz rod insulators. These insulators fit into grooves in the cathode body and are held axially by the end plates so that the anode is firmly supported in a central position. Over the sensitive portion of the counter, each end plate is machined to form a window 0.020 in. thick. Thus apart from the uranium deposits there is only 0.052 in. of aluminum to attenuate the neutron beam. The deposit thickness is ~0.1 mg/cm² and depends on the neutron flux to be measured. The anode seal is similar to that of the Type 1 counter, but is sealed into the cathode body with Araldite Type I.* The anode-to-cathode spacing (0.45 in.) is such that counting-gas pressure can be just below atmospheric. This reduces the stress to which windows are subjected.

Since this counter is used to measure the total intensity of the neutron beam, it is important that the uranium film be uniform. This is achieved by a previously described technique (*16*).

Evacuation and Filling

The tubulation on the glass seals serves for evacuation and filling. Both counters are evacuated to pressures of 10^{-6} mm of Hg. The Type 1 counter is outgassed by heating to 400° C for ~1 hr, and the Type 2 to 150° C for ~3 hr. The gas filling used for counters in which a very high counting rate is not required is 99.9% pure commercial welding argon, while for highest counting rates a 90%-argon-10%-methane† mixture is used. Sealing off is performed at present with pressure in the counter reduced to below atmospheric by liquid-nitrogen cooling. We are planning to change to an aluminum-tubulation pinch-off.

PERFORMANCE

The Type 1 counter was designed primarily to replace the BF_3 counters used in the start-up experiments of the Chalk River reactors. For this application it offers the following advantages over the BF_3 counter:

1. Pulse rise time of the fission counter (0.060 μsec for an argon-methane filling) is much faster than that of BF_3 counters (3–4 μsec) (*17*).

2. Operating voltage of the fission counter is much less than that of the BF_3 counter. Since no gas gain is used, the output pulse is largely independent of voltage. The size of the pulse from a fission counter is about the same as that from a BF_3 counter operated normally at low gas gain.

3. The fission counter can be operated satisfactorily in a gamma flux of at least 10^5 r/hr. The BF_3 counter is limited to 10^3 r/hr and in this flux suffers rapid deterioration.

4. Initial costs of both types are about the same. However, due to the simple construction and non-corrosive gas filling, the fission counter is more easily repaired if damaged.

Boron-coated pulse proportional counters compare more favorably with the fission counter. They do not show the deterioration in high gamma fields exhibited by the BF_3 counter. Boron-coated counters use argon as the counting gas, and unlike BF_3, argon does not lose its counting properties when it is irradiated.

However, since only one fragment—either the lithium nucleus or the alpha particle—is available to ionize the gas, the pulse size is about ½ of that obtained from an equivalent BF_3 counter. Also the difference between initial energies of the two particles and the energy spread from their partial absorption in the boron coating give rise to a much worse defined pulse-amplitude-distribution curve than can be obtained with a BF_3 counter (*18*).

The Type 2 counter was designed as a replacement for a BF_3 counter to monitor the neutron beam from the experimental hole of a reactor. A BF_3 counter is not particularly suitable for this application since it is difficult to make an insensitive BF_3 counter with good pulse-amplitude distribution characteristics (*18*).

The counters have been tested with especially designed electronic circuits. The curves of Figs. 4–9 show the results.

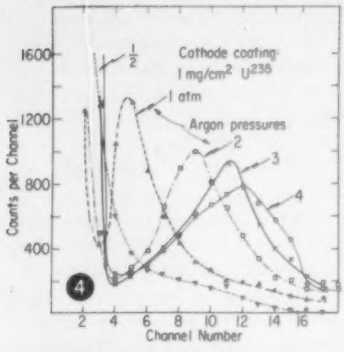
Test Electronics

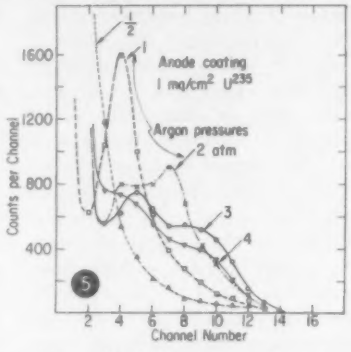
A high-gain linear-amplifier chain consisting of an Atomic Instruments Co. Preamplifier Model 205B and an AECL Type AEP 1444 Linear Amplifier (*19*) provides necessary amplification of the counter pulse. The pulse spectra are obtained on an 18-channel kicksorter (*20*). Adjustable *RC* time constants are built into the linear amplifier, but since delay lines offer some advantage over *RC* pulse shaping, the alternative of a 0.150-μsec delay line was made available by replacing the Atomic Instruments pre-

* Obtained from CIBA, Montreal.

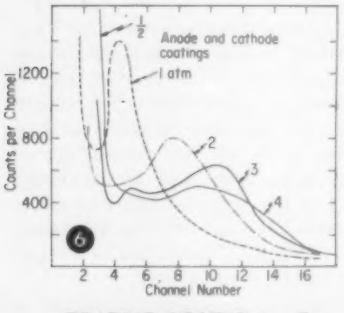
† Argon 99.9% pure, methane C.P. grade—better than 99% pure.

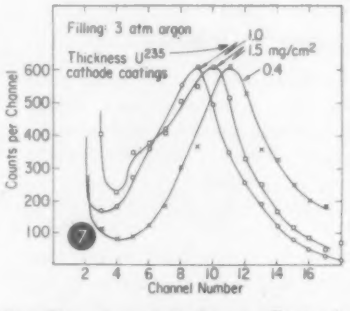
Fission-Counter Performance Depends on . . .



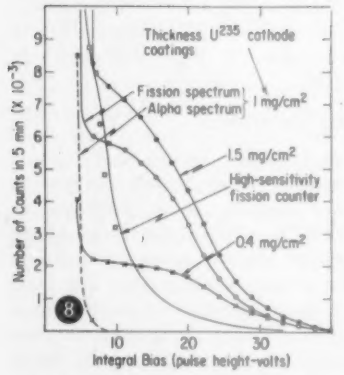


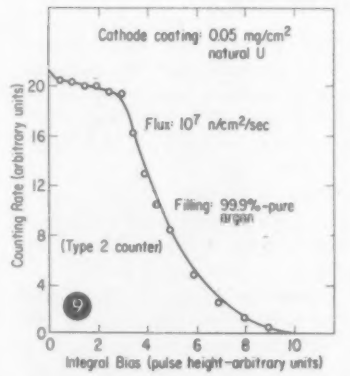
. . . FILLING PRESSURE. Best fission-alpha discrimination with cathode-coated, argon-filled counter is at 3 atm (Fig. 4). If anode is coated, least unsatisfactory discrimination is at 1 atm (Fig. 5) . . .





. . . COATING POSITION. Comparing Figs. 4 and 5 shows effect of moving coating from anode to cathode. Their sum (Fig. 6) shows response of doubly coated counter. COATING THICKNESS. Discrimination suffers if fission fragments lose appreciable energy in thick coating (Fig. 7) . . .





. . . DISCRIMINATOR BIAS. Integral-bias curves for Type 1 counter are flatter than response of high-sensitivity counter (21) (Fig. 8). Integral-biased Type 2 counter has good plateau in 10^7-n/cm²/sec flux (Fig. 9)

amplifier with an especially designed wide-band preamplifier.

To measure the pulse rise time the wide-band preamplifier was used with a Hewlett-Packard Model 460A distributed amplifier and a Model 545 Tektronix Oscilloscope.

Pulse Spectra

The counters were tested in a slow-neutron flux of 10^2 n/cm²/sec obtained from three Pu-Be neutron sources embedded in paraffin. For the Type 1 counter, the amplifier rise and fall time constants were 0.2 μsec, the anode potential 250 volts, and the filling gas 99.9%-pure argon. Over the range of filling pressures investigated, the chamber collection time (0.7 μsec)* changed by less than 0.1 μsec. Although amplifier response is faster than collection time, the fast differentiation is not appreciable, and except for the alpha pile-ups similar spectra would have been obtained with any slower amplifier setting.

A 0.150-μsec delay line was used to differentiate the voltage pulse of an argon-filled, cathode-coated fission counter in an attempt to improve the pulse spectra by eliminating the positive-ion-induction effect. As already indicated the expected improvement is small. Within the accuracy of the experiment there was no significant difference between spectra obtained with fast differentiation by the delay line and slow differentiation with a 1.0-μsec *RC* time constant. In both cases the high-frequency response of the amplifier was not artificially restricted.

Type 1 performance. Figures 4–8 show performance of Type 1 counters. Figure 4 shows that a pressure of 3 atm (absolute) gives a satisfactory pulse-amplitude distribution. At 0.5 atm there is poor fission-alpha discrimination. In Fig. 5 at pressures above 1 atm there is a suggestion that light and heavy fission fragments are being resolved. Below this pressure there is little fission-alpha discrimination. The curves of Figs. 4 and 5 are taken with identical amplifier conditions, and their sums (Fig. 6) give the characteristics of a counter with both anode and cathode coated. The results are

* The drift velocity is almost twice that obtained by Nielson [*Phys. Rev.* **50**, 950 (1936)], whose results are confirmed by other workers (e.g., see Bortner *et al.*, Ref. 10). This is an expected result of trace impurities.

poor enough to act as a deterrent to coating both anode and cathode. Direct measurements gave confirmatory results.

Figure 7 shows pulse-amplitude curves for three Type 1 counters with different thicknesses of cathode deposit. The curves were obtained by counting for different times to give the same number of counts in the peak channels. Identical amplifier conditions were used, but since there were small variations in the chambers, the position of the peak channel on the kick-sorter varied slightly. The peak-to-valley height ratio and the general width of the valley are the important points. These curves indicate the desirability of using a deposit thickness not greater than about 1.0 mg/cm² and preferably about 0.5 mg/cm².

Figure 8 illustrates typical integral-bias curves. Plateau length becomes shorter as deposit thickness increases. Minimum plateau slopes are 1.1% per volt for 0.4 mg/cm², 2.1% for 1 mg/cm² and 2.9% for 1.5 mg/cm². These values have been normalized so that inflection points correspond to a pulse height of 10 volts. The high-sensitivity counter (*21*) mentioned in Fig. 8 contains 12 times as much fissionable material as the 1.0-mg/cm² counter. This curve was measured under the same conditions as for other counters but with ⅛ the neutron flux. Above 50 cpm the alpha background curve for the counter is coincident with that of the 1-mg/cm² counter, and the measured pulse height at a particular alpha counting rate enables comparison of published and measured fission-bias curves. The points shown on the curve for the high-sensitivity counter are calculated from published data. The poorer characteristic of this counter probably results from coating the anode as well as the cathode and from using too thick a coating of the fissionable material.

Type 2 performance. Figure 9 is obtained from a Type 2 counter. Amplifier rise and fall time constants were 0.7 and 5.0 μsec, respectively, and the anode potential 250 volts. Natural uranium is used since only a small amount of fissionable material is required.

Sensitivity and Background

For a Type 1 counter with a cathode coating of 1 mg/cm² of U^{235} on an area of 120 cm², the alpha pulses can be effectively biased off with a loss of only 6% of the fission counts. The resulting rate is 0.2 cps for a neutron flux of 1 n/cm²/sec. Background counting rate due to spontaneous fissions can be calculated from known half-lives of U^{235} and U^{238} (*22*) to be 0.31 ± 0.13 count/hr. Our measured background counting rate is 0.6 count/hr.

An argon-methane-filled fission counter will monitor over a 10^6 range provided the accuracy requirements are not too rigid. Thus if 1 cps is taken as the lower rate, a 13% statistical accuracy is obtained by counting for 1 min, while if the response time of the amplifier is taken as 0.2 μsec and a 10^6-cps counting rate is obtained, the true rate is 1.25×10^6 cps.

High gamma fields. The Type 1 counters have been used to measure neutron fluxes of approximately 10^2 n/cm²/sec in the presence of gamma fluxes of 10^5 r/hr. They have suffered no observable deterioration after being exposed to an irradiation of 2.4×10^7 r.

Counting Life

The counters have been subjected to an accelerated life test in the NRX Reactor at Chalk River. This test was the equivalent of operation at maximum counting rate for a 10-yr period, or an irradiation of 1.6×10^{15} n/cm². There was no observable change in the electrical characteristics of either the argon- or 90%-argon–10%-methane-filled counters. The Pyrex glass forming the anode seal was darkened, however, and a week after irradiation the gamma activity (mainly from fission products in the counter) was 60 mr/hr at the surface.

To determine whether the pulse rise time of the 90%-argon–10%-methane filling altered under neutron irradiation, a counter with this gas mixture was subjected to a 40-yr equivalent life. Over this time the pulse rise time doubled.

APPENDIX—Cu-Al Braze

For the copper-to-aluminum braze,* the copper and aluminum are first chemically cleaned (*23*). The parts are then fluxed and assembled with a ring of C 35S aluminum alloy filler rod around the copper tube. This assembly is placed in an oven at 650° C until about 1 min after the filler rod has melted. In the formation of the joint, it appears that the filler-rod melting enables some copper and pure aluminum to go into solution.

A photomicrograph† shows the bond as copper, then probably a compound of copper and aluminum, and, adhering to this, crystals of the *K*-phase solid solution of copper and aluminum (*24*). Beyond this again is a eutectic of the θ- and *K*-phase solid solutions with crystals of the *K*-phase solid solution and finally aluminum. The eutectic constitutes a brittle intermetallic layer, but if this is kept thin (of the order of 0.008 in.) by controlling time, the joint is satisfactory.

* * *

The author acknowledges his indebtedness to H. Carmichael, I. L. Fowler, G. C. Hanna and P. R. Tunnicliffe for helpful discussions, to D. R. MacKenzie for help with the deposition of the uranium and to B. W. Brammall and R. Toone for assistance during the project.

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* H. R. Huffman, metallurgy branch of this laboratory, first suggested the feasibility of the joint, and R. R. MacLanders using an oxyacetylene torch was able to make one vacuumtight.

† The metallurgical specimens were prepared and photographed by the Chemical and Metallurgical Division of this laboratory.

Paramagnetic Resonance Shows Radiation Effects

By HAROLD C. BOX and HAROLD G. FREUND, *Roswell Park Memorial Institute, Buffalo, New York*

Paramagnetic-resonance spectroscopy (*1*) is a useful method for studying irradiation effects in solids (see box, p. 68).

The normal pairing of electrons can be disrupted by ionization or by the dissociation of a chemical bond due to molecular excitation. Thus in many organic solids irradiation produces quantities of surprisingly stable unpaired electrons. Paramagnetic-resonance studies are helpful in identifying free radicals with which unpaired electrons are associated (*2*). Paramagnetic resonance spectroscopy does not afford a positive identification of the free radicals formed in irradiated compounds; however, a considerable amount of detailed information concerning them can be obtained. No other technique permits such a direct study of this phase of radiation damage to the condensed state. Combined with conventional experimental techniques, paramagnetic-resonance spectroscopy will undoubtedly add to our understanding of radiation chemistry.

The simple paramagnetic resonance spectra presented here seem to originate from a single type of radical. The whereabouts of the complementary electron from the divorced pair is unknown. A study of the gases produced in the irradiated materials may help to answer this question.

Amount of Absorption

Resonance absorption is proportional to the number of unpaired electrons in the irradiated sample. Adhering to the convention of radiation chemistry we define a G-value as the number of unpaired electrons produced in the irradiated sample per 100 ev of absorbed energy. Hence, $G = (100k\int P(H)dH)/DW\alpha$, where $\int P(H)dH$ is the resonant absorption of microwave power integrated over the width of the absorption, D is the total dose, W is the weight of the sample in grams and α is the value of unit dose in electron volts per gram. The calibration factor k is determined by measuring the absorption by a stable paramagnetic substance containing a known number of unpaired electrons.

The integral $\int P(H)dH$ and k must be determined under the same experimental conditions. We use chromium chloride, a paramagnetic salt containing three unpaired electrons per ion, for calibration. Measurements of G values are probably accurate to within a factor of 2. The value of α for hydrocarbons can be taken as 58×10^{12} ev/gm/r (*3*).

Fig. 1 is a photograph of our apparatus.

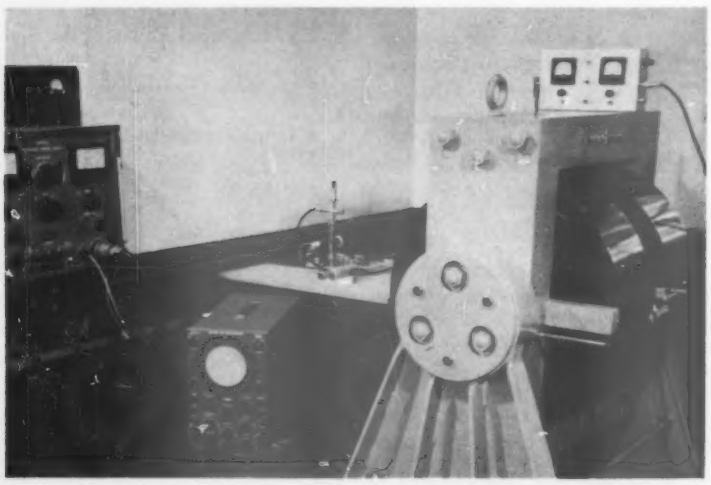

FIG. 1. Paramagnetic-resonance apparatus uses klystron source of microwaves, variable electromagnet and resonant cavity containing sample

G-values. The G-values we find for a number of X-irradiated organic compounds, mostly of biological interest, are given in Table 1. Presumably the unpaired electrons detected here are the odd electrons on free radicals produced by irradiation. In organic materials a G-value of 3 corresponds roughly to one stable radical produced for each ionization or—more appropriately perhaps—one stable radical produced for every three molecular excitations.

Charged radicals produced by ionization are thought to be unstable in irradiated organic materials because no effective means for trapping the ionized electron exists (*4*). On the other hand organic radicals formed by dissociation of excited molecules might also be expected to recombine. Considering the reactive character of free radical species the yields given in Table 1 are surprisingly high for many of the compounds. The irradiations and subsequent measurements reported here were carried out at room temperature. All of the factors responsible for stabilizing the

TABLE 1—G-Values from Paramagnetic Resonance

Amino acids	*G-value*
Glycine	0.7
Alanine	0.9
α-Amino *n*-butyric	0.3
α-Amino isobutyric	0.5
Norvaline	<0.1
Leucine	0.5
Isoleucine	0.4
Norleucine	0.6
Cystine	<0.1
Cysteic acid monohydrate	2.6
Peptides	*G-value*
Glycyl glycine	2.3
Glycyl glycyl glycine	1.3
Alanyl glycyl glycine	0.9
Leucyl glycine	0.8
Alanyl alanine	0.5
Glycyl alanine	0.7
Alanyl valine	0.9
Glycyl leucine	<0.1
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Glycyl glycyl leucine	<0.1

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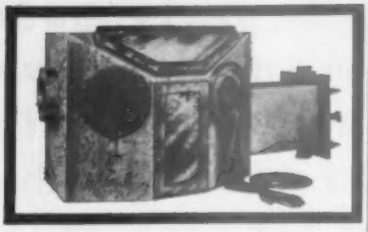

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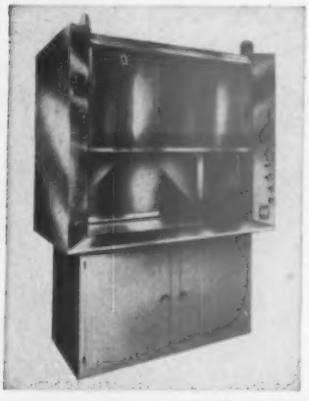

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INSTRUMENTATION AND MEASUREMENTS

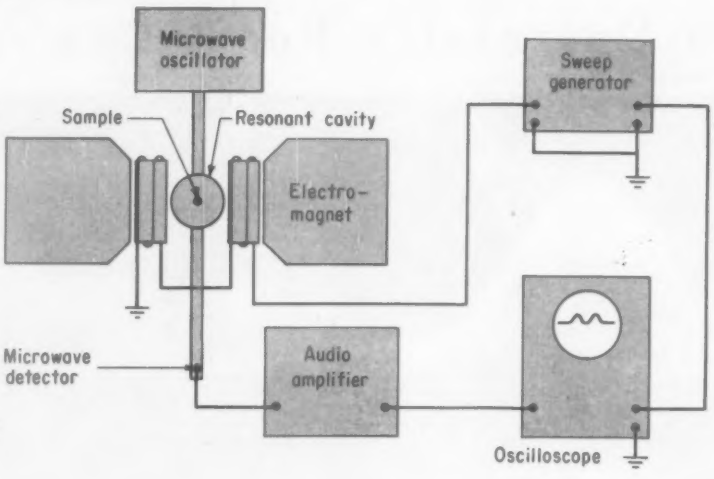
This article starts on page 66

radicals are not known, but it is certain that lower temperatures would stabilize additional free radicals too transient to be observed at room temperature. At temperatures approaching absolute zero even extremely reactive species such as atomic nitrogen can be stabilized (*5*).

Fine Structure

Often the paramagnetic-resonance spectra contain additional structure not accounted for by the simple resonance condition expressed by Eq. 2. (*See box.*) Structure can usually be attributed to the influence of nuclei in the vicinity of the odd electron. It is convenient to distinguish two types of perturbation—Fermi and dipole-dipole interactions—that can produce hyperfine structure (*6*).

The Fermi interaction between an electron and its associated nucleus occurs if the odd electron has at least a partial *s*-state character and if the nucleus has a magnetic moment. In effect the magnetic field at the electron is altered in a way that depends on the orientation of the nuclear magnetic



Paramagnetic Resonance—How Does It Work?

The resonance phenomenon depends on the angular momentum of the electron and its resulting magnetic moment (*1*). In organic compounds electrons are usually combined in closed shells or in chemical bonds containing pairs of electrons, with only slight magnetic properties. Electrons which for one reason or another are *not* paired can be detected by paramagnetic resonance.

According to quantum mechanics an electron immersed in a magnetic field is allowed only two orientations. The energy of the electron depends on its orientation and is given by

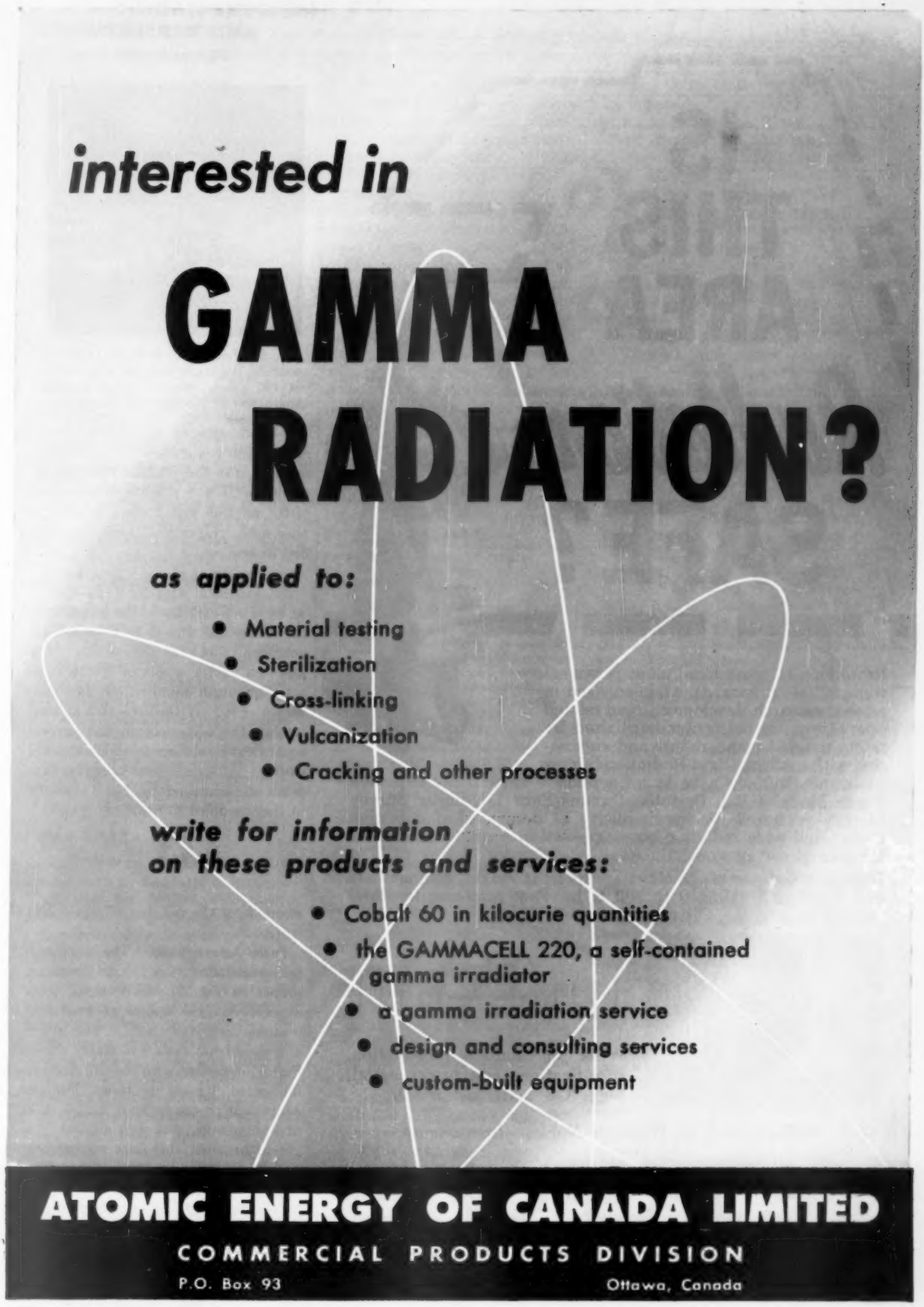
$$E = g\beta HM \qquad (1)$$

where g is the spectroscopic splitting factor, β is the Bohr magneton, $-(eh/\gamma\pi mc)$, H is the strength of the external field and M is the magnetic quantum number of the electron, which has the values $\pm \frac{1}{2}$ depending on the orientation of the electron in the magnetic field.

A high-frequency field at right angles to the static field induces transitions between the two energy levels provided the frequency of the oscillating field satisfies the resonance condition given by

$$h\nu = g\beta H \qquad (2)$$

where h is Planck's constant. For a magnetic field of several thousand gauss Eq. 2 requires a frequency in the microwave region. Since the population is slightly greater in the lower-energy level, more transitions from the lower level to the upper level occur than vice versa, and a net absorption of microwave energy results. In practice the microwave frequency is held constant and the magnetic field is swept through resonance. The experimental arrangement is shown in the accompanying figure.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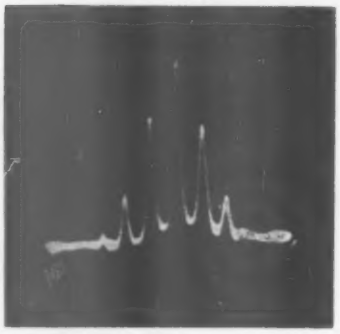

FIG. 2. Fine structure in X-irradiated α-amino isobutyric acid has total width of 110 gauss. Intensity ratios suggest interaction of electron with six equivalent protons

moment. If the nucleus has spin I, there are $2I + 1$ possible orientations of the nucleus with respect to the applied field. Equation 1 must be modified to read

$$E = g\beta HM + aMm \qquad (3)$$

where a is a measure of the strength of the interaction and m is the magnetic quantum number of the nucleus. For a proton having a spin of ½ the magnetic quantum number can take the values $\pm\frac{1}{2}$. If the free radical containing the odd electron has several equivalent structures in which the odd electron through hyperconjugation appears on several nuclei, Eq. 3 must be further modified to read

$$E = g\beta HM + \sum_{j=1}^{N} a_j M m_j$$

where N is the number of equivalent structures.

Fermi interactions. The paramagnetic-resonance absorption spectrum shown in Fig. 2 was obtained from a polycrystalline sample of irradiated α-amino isobutyric acid. The seven absorption maxima are probably due to Fermi interaction with the odd electron influenced by six protons. For six equivalent protons with 0, 1, 2, 3, 4, 5, or 6 components of spin aligned in a given direction there are respectively 1, 6, 15, 20, 15, 6 and 1 possible combinations. These numbers correspond to the ratios of the intensities of the maxima shown in Fig. 2, which represent transitions where the electronic—but not the nuclear—magnetic moments change direction. Thus one of

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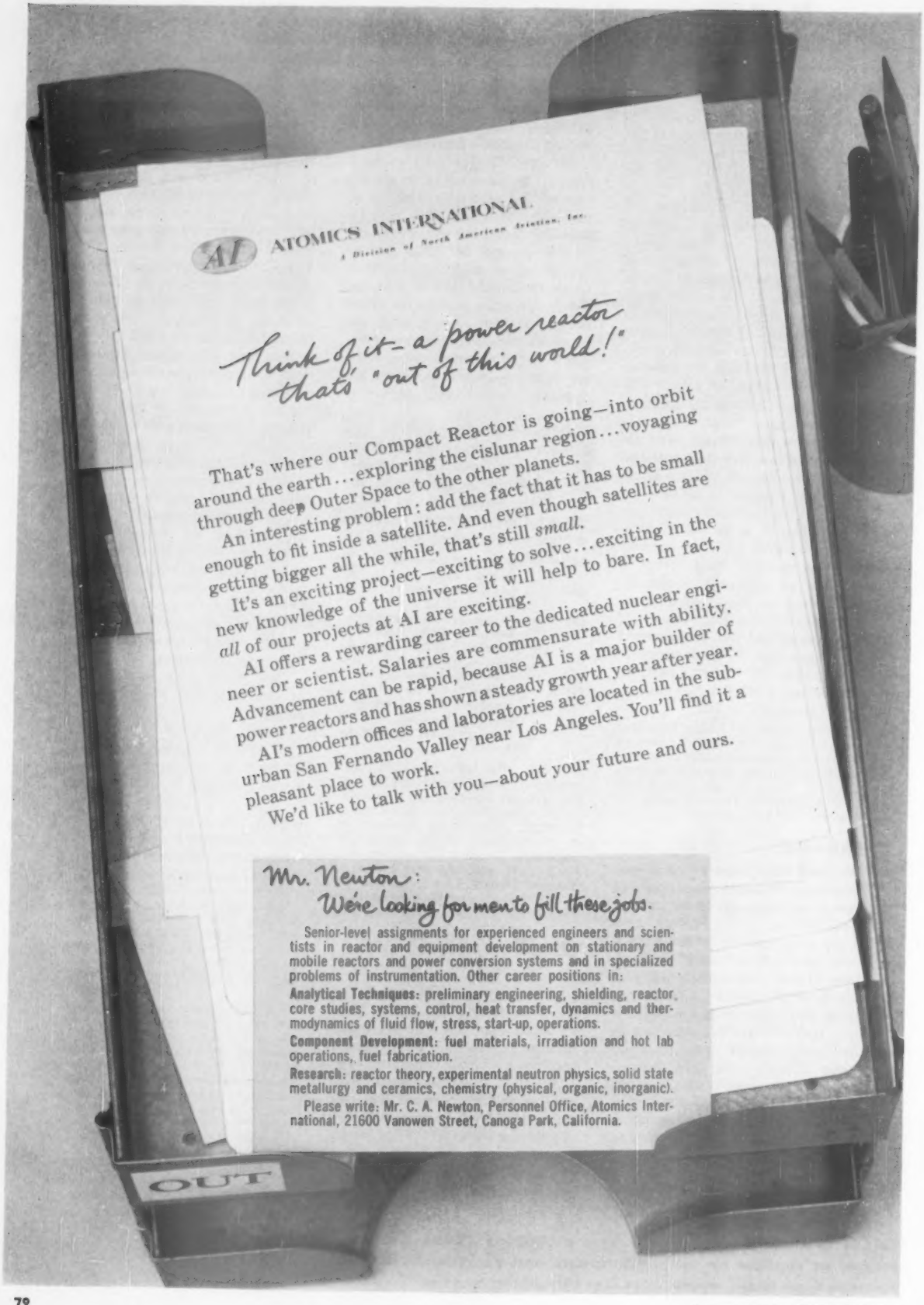
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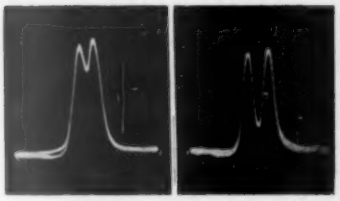
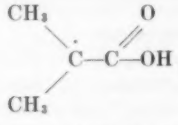


FIG. 3. Spectrum of X-irradiated glycyl glycine in powder form (left) indicates interaction of odd electron and single proton. Single-crystal spectrum (right) shows interaction is dipole-dipole

the fragments formed by irradiation must be a free radical containing all six equivalent hydrogen atoms on the aliphatic stem of isobutyric acid. The zero-spin oxygen and carbon nuclei cannot contribute to hyperfine structure, but the absence of any apparent interaction from the nuclei of the amino group is noteworthy. We postulate the formation of



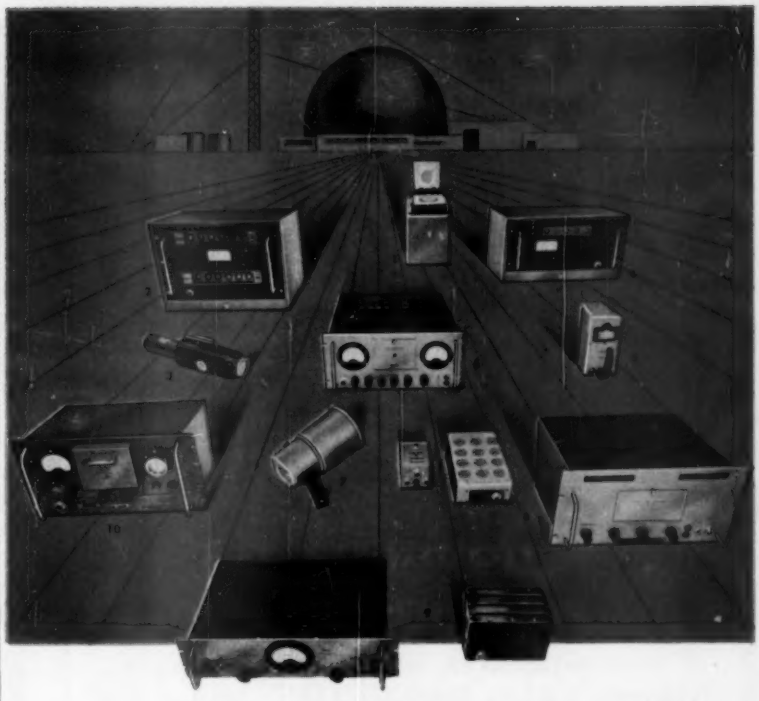
where the weak NH_2 bond has been broken, leaving a radical with the odd electron localized primarily on the alpha carbon atom but having a small probability of appearing on each of the protons of the methyl groups. Somewhat analogous spreading of the odd-electron wave function over a molecule has been reported by Fraenkel (7) for certain aromatic free-radical ions.

Other breakdown products can be postulated for amino isobutyric acid which would also account for the observed spectrum. Calculations of the odd-electron wave-function density and additional experiments are needed to test our interpretation.

Dipole-dipole. A classical magnetic dipole-dipole interaction between the unpaired electron and a nucleus can occur if the electron is in other than an *s* state. For an electron interacting with a neighboring nucleus an approximate substitute for Eq. 1 is

$$E = g\beta M\left(H + \frac{m\beta_N\mu}{I}\,\frac{(3\cos^2\theta - 1)}{r^3}\right) \qquad (4)$$

where r is the separation between centers of electronic and nuclear magnetic dipoles, θ is the angle between the directions of r and the magnetic field, β_N is



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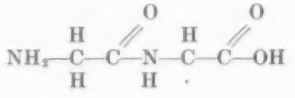
the nuclear magneton and μ is the nuclear magnetic moment.

The paramagnetic-resonance absorption of irradiated glycyl glycine, shown in Fig. 3a, has been reported (*8*) and suggests an interaction between the odd electron and a single proton. Using a single crystal of glycyl glycine we have established that the interaction is mainly dipole-dipole, and the maximum splitting, shown in Fig. 3b, is 24.5 gauss. One obtains the same spectrum if the hydrogen atoms on the carboxyl, amino and amide groups of glycyl glycine are replaced with deuterium. We conclude therefore that irradiation causes the dissociation of a carbon-bound hydrogen atom leaving a free radical of the form



where the odd electron interacts with a neighboring proton.

The paramagnetic resonance spectra of all the irradiated compounds listed in Table 1 except cystine contain structure indicative of one or both types of interaction. No other contains fine structure as well resolved, however, as that shown in Fig. 2 for amino isobutyric acid. We believe the clarity of this spectrum may be due in part to the complete equivalence of all the hydrogen atoms on the aliphatic stem of amino isobutyric acid. It is likely too that some of the amino acids yield several stable free radicals and that their resonance absorptions are superimposed.

Each of the irradiated amino acids yields its own characteristic spectrum. The spectra of the irradiated peptides are often very different from those of the individual constituent amino acids and sometimes simpler. Polycrystalline samples of the first four peptides listed in Table 1 yield doublet spectra. The next three produce quintuplet absorptions suggesting Fermi interaction with four protons. Many of these spectra have been discussed in the literature (*2*, *8*, *9*). Generally, however, additional studies using isotropically labeled compounds and single-crystal specimens are needed to verify the interpretations which have been made. Alanyl alanine, for example, in single-crystal form yields the spectrum shown in Fig. 4, which is similar to that

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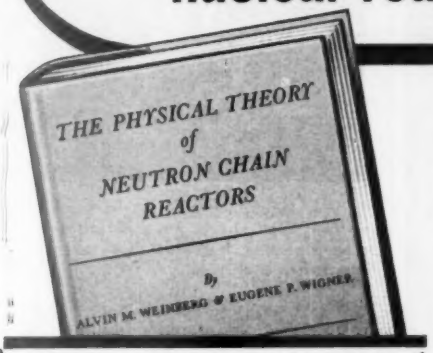

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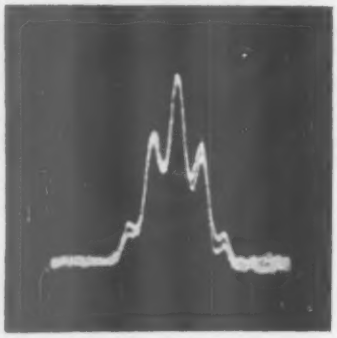

FIG. 4. Broadening of peaks in this single-crystal spectrum of irradiated alanyl alanine indicates that several interactions are present

obtained from powdered alanyl alanine although somewhat better resolved. Upon rotation of the crystal, however, the peaks are considerably broadened, indicating other interactions are present. This and other irradiated organic compounds yielding complex paramagnetic resonance spectra are currently being investigated.

So far attention has been focused primarily on direct radiation damage, but paramagnetic-resonance spectroscopy can be used advantageously to study indirect mechanisms, such as are important in radiobiology. For example, H and OH radicals have been detected in irradiated ice (*10*). These radicals have long been postulated as intermediate species responsible for damage to biological systems. Paramagnetic resonance studies of the mechanism by which certain chemicals are able to enhance or reduce the biological effects of radiation may also be possible.

* * *

This work was supported in part by the Damon Runyon Memorial Fund.

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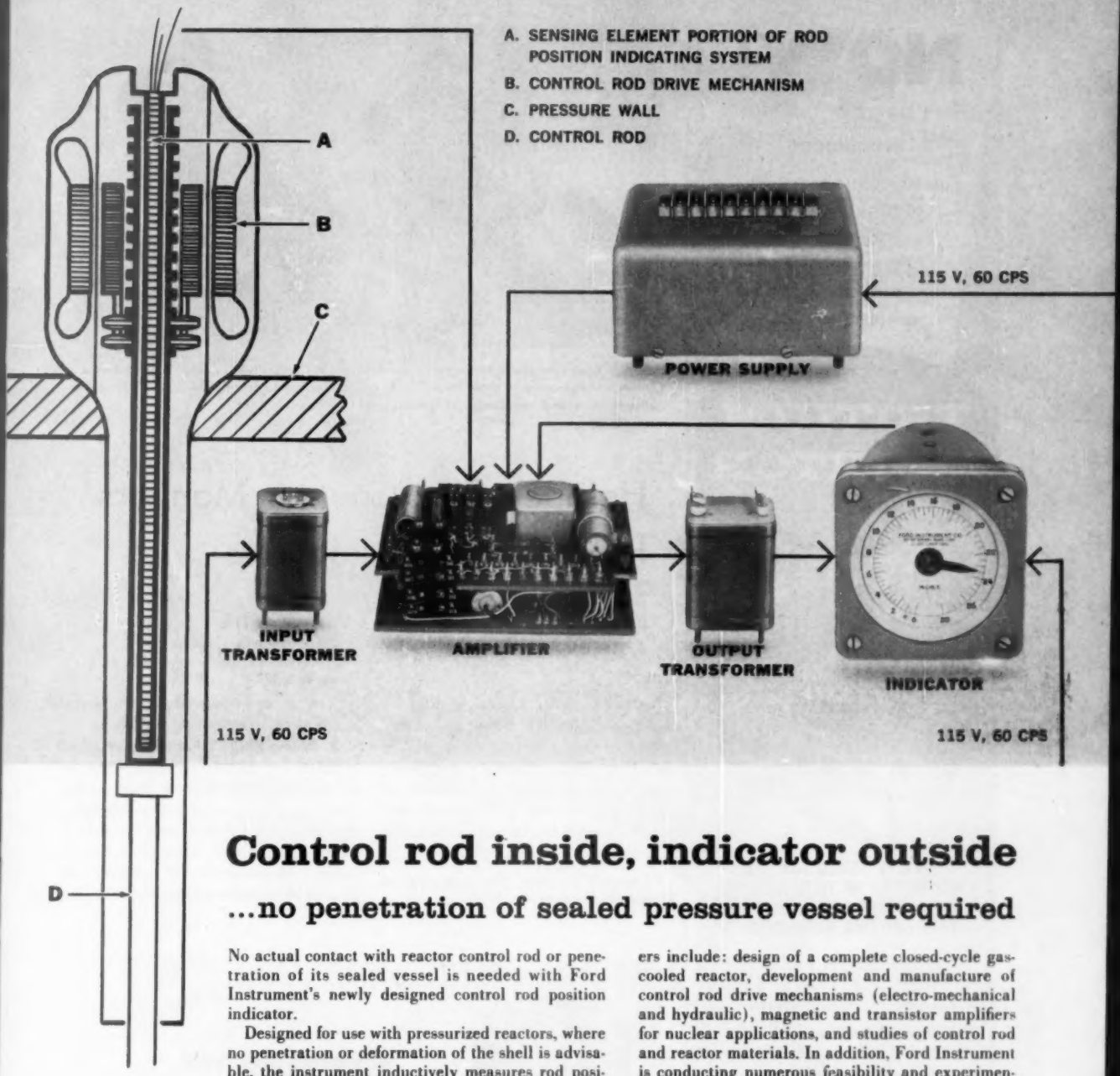

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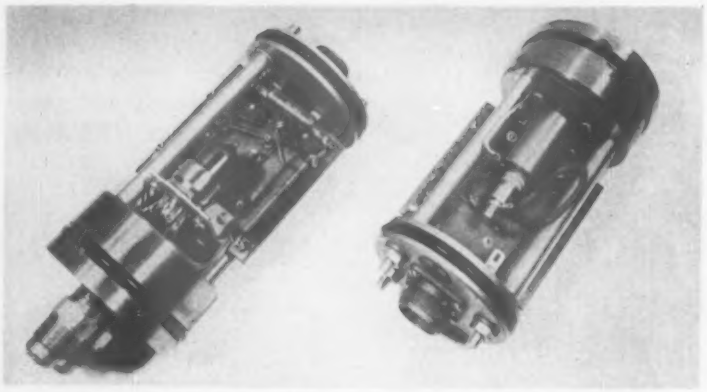

FIG. 1. Beta-counter monitors to detect failures in Chalk River reactor fuel elements. Covers are removed to show (right) HBM counter attached to gas cell and (left) cold-cathode tube and remainder of components

Halogen Beta-Counter Monitors for Chalk River Reactors

By I. L. FOWLER, A. PEARSON and L. A. K. WATT*
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada

In 1953, gaseous-fission-product monitors (*1*) were planned for the detection of faults in rod sheathings in the Chalk River reactors. For these, a beta-sensitive detector capable of measuring a wide range of activity was required so that faults could be detected as soon as they occurred and a measure made of their rate of development.

A low-voltage, halogen-quenched counter was considered as the detector for the following reasons: It is a relatively simple device, requires a straightforward circuit, has a long life and is little affected by intense radiation fields. Moreover, it will operate both as a pulse counter and as a current de-

* PRESENT ADDRESS: The University of Minnesota, Minneapolis, Minn.

FIG. 2. Complete monitor. Indicating unit (right) contains alarm or trip circuits operated by special meter

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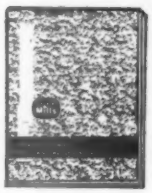

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This article starts on page 78

vice (*2*), thereby giving it a much wider range of measurement than an organic-quenched G-M counter. For convenience in monitor installation, an end-window-type design was chosen.

Counter Design*

It was necessary to have a window at least ¾ in. in diameter. However, a conventional end-window design with a right-cylindrical cathode was unsatisfactory since the ionization current in a high-radiation field was limited to a few microamperes.

Work on other halogen counters had shown that, unlike conventional G-M counters, their working voltage was relatively insensitive to variations in anode and cathode diameters. Accordingly, a conical cathode design was made in which the anode diameter remained constant and the cathode diameter tapered over a length of 1.62 in. from 0.78 in. at the window end to 0.25 in. at the other end. This tapering did not significantly lower the beta sensitivity, and the counter readily provided a current of 50 μa or more in a high-radiation field.

Stability, however, then became a problem. On occasions, as the radiation field increased, these counters would suddenly start to pass a maximum current and continue to do so even when removed from the field. This defect was overcome by using a

* This design (*3*) is the subject of patent applications.

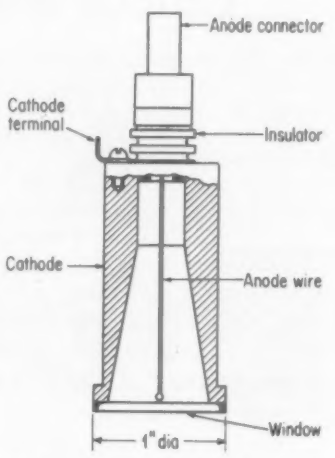

FIG. 3. Design of type HBM halogen beta counter

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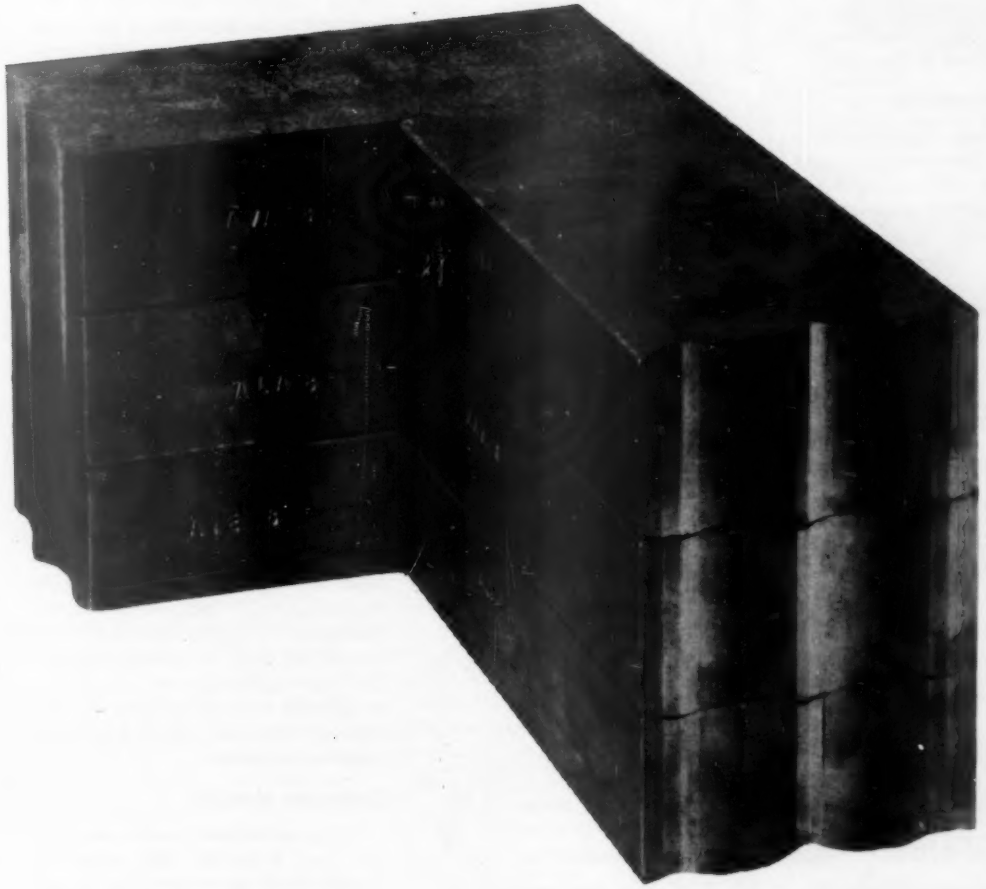

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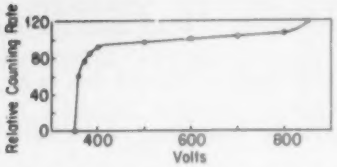

FIG. 4. Typical plateau characteristic of type HBM counter

compound cathode shape—partly conical and partly cylindrical.

The final dimensions and the neon-argon-bromine filling were chosen to allow operation at 460–500 volts and, with a load resistance of 2.2 megohms, to obtain a transition from pulse counting to current measurement at about 50,000 cpm and 5 μa. This point is the start of the logarithmic portion of the current characteristic and suits a special wide-range ratemeter circuit designed for the monitor. The counter (Type HBM) is shown in Figs. 1–3.

Counter Characteristics

A typical plateau characteristic is shown in Fig. 4. The starting voltage* is about 350 volts, the plateau length about 400 volts, and the plateau slope about 5%/100 volts. A typical current characteristic, taken for convenience with gamma radiation, is shown in Fig. 5. The counting rate as a pulse counter is also indicated on this curve.

Counters were life-tested to check the stability of their characteristics. An on-off schedule was adopted with the time on (running time) rather more than the time off (shelf time). During running (in a 10-r/hr gamma field), the current through the counters was set at 45 μa. This is twice the maximum current employed in use and over 50 times the normal average current.

Figure 6 shows the variation in plateau characteristics of one counter over a 3½-year period during which it operated for 16,400 hr—equivalent to probably much more than 10^{12} counts; shelf time was 550 days. In the running time, the counter incidentally received a gamma irradiation of about 1.6×10^{5} r. The counter still has excellent characteristics, and other counters tested for similar long periods changed even less.

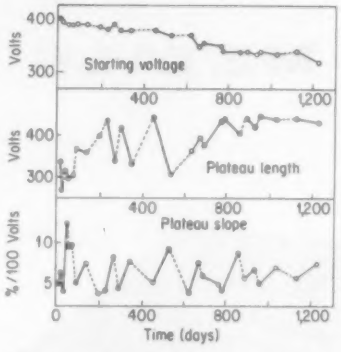

FIG. 6. Variation of plateau characteristics with life

Figure 7 shows the current characteristics of another counter, taken initially and after 720 days or 17,300 hr running on life test. The curves were taken at the same overvoltages to compensate for the fact that, as will be seen from Fig. 6, the starting voltage decreases slowly with life, presumably due to gradual absorption or chemical combination of the halogen component of the filling.

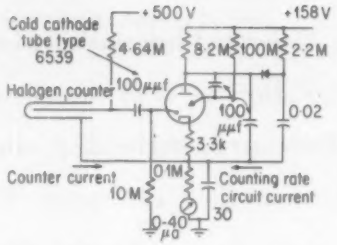

FIG. 8. Wide-range cold cathode tube ratemeter circuit

Monitor Circuit*

The circuit devised to make use of the "two-mode" operation of the counter is shown in Fig. 8. An important feature is simplicity, the only tube being a long-lived, cold-cathode trigger tube (type 6539), which is used in a counting-rate circuit (*5*).

The output from the counting-rate circuit is a current approximately proportional to the logarithm of the counting rate, and to this is added the ionization current of the counter. The counting-rate current saturates to a constant value at the irradiation intensity at which the counter current becomes appreciable. This requires a proper choice of circuit components in relation to the counter characteristics. The two currents then combine to give a smooth logarithmic relationship to the radiation intensity as shown in Fig. 9.

In the ratemeter circuit shown, the counter current has been limited to a maximum of 20 μa and the over-all characteristic to about 3 decades (from 10^3 cpm to the equivalent of 10^6 cpm). In the reactor monitor application, a high background counting rate, of the order of 10^3 cpm, is normal. There is thus no point in making the instrument range the full 5 decades from 10 to the equivalent of 10^6 cpm and thereby reducing the reading accuracy in the portion of the range of greatest interest. For other applications the circuit may be modified to cover a different or the full range and used with other halogen-quenched counters.

Complete Monitor

In a gaseous-fission-product monitor (see Figs. 1 and 2), the counter is mounted with its window close to and

* "Starting voltage" here is the voltage at which the counter pulse triggers a convenient test circuit. With a 4.4-megohm anode resistance, the counter pulse is about 70 volts at the "starting voltage." All other terms used correspond generally to those in IRE Standard 52 IRE 7.S3.

* This design (*4*) is the subject of patent applications.

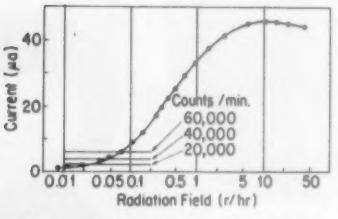

FIG. 5. Typical current characteristic of type HBM counter (operating voltage, 460 volts; load resistance, 2.2 megohm). Gamma source was used

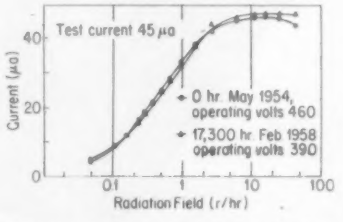

FIG. 7. Current characteristics before and after intermittent life test of nearly 4 yr; total running time at high current, 17,300 hr

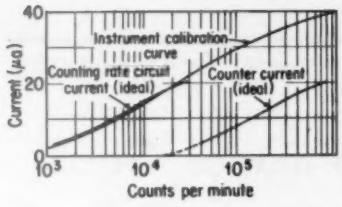

FIG. 9. Typical calibration curve of monitor

facing a thin window in a stainless steel gas cell connected in the sampling line from one or more fuel elements. The monitor head attaches to the gas cell and contains the counter and all the circuit except the indicating meter. A common power supply feeds a bank of monitors.

Discussion

The monitor described provides a very simple means of measuring a wide range of beta and gamma activity. Life tests and operational experience to date have been good.

The range can be further increased without sacrifice of over-all simplicity by additional modification of the counter electrode shape. By this means, the characteristic can be made to cover at least 6 decades. The logarithmic scale demands a much higher degree of accuracy in calibration than a linear scale and the problem is greater as the number of decades increase. However, a portion only may be selected for display to suit a particular application. Thus, when it is required, the whole range can be covered, without switching, by essentially the same instrument.

* * *

The form of monitor shown in the photographs is due to Engineering Design Branch, Atomic Energy of Canada Limited.

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The Activation of Antimony in Adhesive Products

By H. R. LUKENS, Jr.
Shell Development Company, Emeryville, California

A potential radioactive hazard was encountered subsequent to a 30-day pile irradiation of some steel samples at a thermal neutron flux of 5×10^{11} n/cm²/sec.

The hazard was caused by the use of (1) black plastic electrical tape to seal the sample containers, and (2) adhesive radioactivity warning labels to provide immediate postirradiation radioactivity warning. During activation of the steel sample, the tape and labels developed enough activity to measure about 100 mr/hr at 1 ft several weeks later, and in addition these adhesive materials became brittle and powdery.

Half-life and gamma-energy determination, the latter with 3-in. NaI crystal and Penco 100-channel analyzer, indicated that the offending isotope was 60-day Sb^{124}. Postirradiation decay had reduced the 2.8-day Sb^{122} to a minor constitutent. Comparison of tape and label spectra with Sb^{124} obtained from ORNL confirmed the identification of antimony. In addition, fresh tape samples were irradiated with a Van de Graaff neutron source [$Be(\gamma,n)2\alpha$] for 30 min at a flux of 5×10^7 n/cm²/sec with the result that Sb^{122} was produced and identified in the tape.

It is estimated that the tape and labels contained as much as 1 wt% antimony, enough to produce about 1 mc Sb^{124} per gram of material in 30 days at 5×10^{11} flux. The use of any adhesive materials such as these should be preceded by an assessment of this potential hazard.

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Russians Review Aircraft-Reactor-Performance Goals

A recent Soviet publication* reviews Russian ideas about the design of nuclear-powered aircraft. Although the volume was written for their "Popular Science Library" and hence is tutorial in aim, it includes enough technical detail to leave the reader with a pretty fair picture of what is needed in terms of performance for a successful aircraft reactor.

The report begins by pointing out that a 150-ton nuclear airplane with advanced aerodynamic form flying at the speed of sound and an altitude of 11 km (35,000 ft) would require a reactor power plant output of about 300 Mw(th). To fly the same airplane at the same altitude at Mach 1.5 would require 900 Mw. A divided shield would account for about 70 tons of the total weight.

Extreme fuel temperatures in the reactor are inescapable, both to achieve the high power density implied by the total power requirement and to keep the jet-exhaust temperature reasonably high. Rough calculations show that a nuclear airplane to have the same flight characteristics as modern chemical-fuel aircraft would have to operate its reactor fuel-element surfaces at no less than 1,000° C (1,830° F).

Reminiscent of the U. S. ANP program (NU, June '57, 21), the Russians propose two different types of reactor-turbojet systems—a direct-cycle system (in which the air flow cools the reactor core directly) and a liquid-metal-cooled system (in which an intermediate coolant loop removes the reactor heat and transfers it to the air). The reactor design concepts proposed for each system would produce 300 Mw(th) over a core lifetime of 500 hours (a burnup of 6.5 kg U^{235}).

Direct-Cycle Thermal Reactor

In one version of the Russian direct-cycle reactor the core would be a cylindrical homogeneous mass of U^{235}-beryllium alloy pierced by 17,000 air-flow tubes. The latter have an i.d. of 10 mm (0.4 in.) and are made of "heat-resistant nickel alloy." The core is 1.9 m (6.2 ft) in diam and length with a 15-cm side reflector of Be metal and 10-cm end reflectors. The air channels would have a maximum surface temperature of 1,100° C (2,012° F) and would heat the air to 950° C (1,740° F). [The melting point of Be is 1,315° C (2,400° F).] The fuel charge contains 70 kg of U^{235} and 2,000 kg of Be; the combined weight of the core and reflector is 9,500 kg. The reactor is controlled by inserting control plates along six equally spaced radial surfaces.

Li-Cooled Fast Reactor

The fast-reactor design proposed by the Soviets for the indirect cycle would be cooled by liquid lithium [m.p. 180° C (336° F), b.p. 1,320° C (2,400° F) at atmos. press.] The Li flow enters at the middle of the cylindrical core and divides itself between the two halves. In each half it first flows to the end of the core through the insides of an array of tubular elements and then back over the outsides of the elements to an exit on the side. From here it is piped to the Li-to-air heat exchanger that replaces the combustion chamber in the turbojet engine.

With a maximum fuel element surface temperature of 1,000° C (1,830° F), the inlet and outlet Li temperatures are quoted at 750° C (1,380° F) and 950° C (1,740° F). The diameter and length of the core are both 0.8 m (2.6 ft). The tubular fuel element has an o.d. of 8 mm and an i.d. of 4 mm; the "nickel-alloy" cladding has a thickness of 0.5 mm and the 50%-enriched-U meat a thickness of 1 mm. A control rod is located along the axis of the core. The core contains 900 Kg of structural material and 1,100 kg of enriched U (550 kg of U^{235}). The dry weight of the reactor with control system but not including a reflector is 4,000 kg. The system is pressurized at 20 atm.

The Soviets consider fuel-element integrity the major problem to be solved in developing reactors such as described. Perspective fuel materials must have good structural properties up to at least 2,000° F and at the same time be corrosion resistant to the air or liquid-metal coolant.

Aviation Week, a McGraw-Hill publication, recently carried a report that the Soviets are already flight testing a plane with nuclear-powered engines. According to *Aviation Week*, the new engine is a direct-cycle type with performance figures similar to those of the direct-cycle system described above.

* G. N. Nesterenko, A. I. Sobolev, Yu. N. Sushkov, "Application of Atomic Engines in Aviation," (Military Press of the Ministry of Defense of the USSR, Moscow, 1957). Translation available from Office of Technical Services U. S. Dept. of Commerce.

Primer on Reactor Fuses

The time requirement for operation of a reactor safety fuse depend largely on the power level at which the fuse starts to operate—the time available for shutting down the reactor is much less for fuses activated at high power levels than for fuses activated at low power levels. To stop a short-period excursion before it reaches 10^4–10^6 times normal power an internal fuse should fire at a low power level in a time of the order of magnitude of the shortest period a reactor would have during a runaway. The shortest period considered possible during an excursion is about 2 msec; thus 5 msec or less is a practical fuse-reaction time.

Internal fuses can be divided into two classes: those that derive all of their energy of action from nuclear fission and those that use the energy of fission to trigger an auxiliary energy source to complete their action. In general, fuses of the first class have the advantage of maximum simplicity. Fuses of the second class have the advantage of operating at a considerably lower power level and in a much shorter time. A fuse of this type might be required to move a 4-oz charge of poison at a velocity of 1,000 ft/sec.

An internal fuse of the second class can be divided into the following parts: a) trigger—a sensing device that gives a signal when the flux or temperature

exceed a given level; b) primer—a device that initiates the action of the main auxiliary energy source (propellant) when the trigger gives a signal; c) propellant—the auxiliary energy source that disperses the poison, or ejects fuel or moderator; and d) poison.

In some cases it is possible to omit one or more of these parts, with the speed of response being improved thereby. The total energy required to disperse poison in a reactor may be reduced by selecting the poison that makes the greatest change in reactivity per gram of poison. Both natural boron and B^{10} are among the best poisons for thermal reactors. The poison must be finely dispersed to reduce self-shielding.

A trigger for an internal fuse that is actuated only by a short reactor period can be constructed from a bimetallic element made of plutonium and some other metal with the same thermal-expansion coefficient. The heat developed in the plutonium by a short-period-flux increase will not have time to diffuse into the other element, hence, the element will bend and can be made to complete an electric circuit. The heat in the plutonium developed by a long-period-flux change will, on the other hand, heat the whole element, and no action will occur. Such a trigger can be actuated by a temperature difference of <1–$2°$ C.

Bimetallic elements can be built to buckle with a speed of about 3,000 ft/sec, so that the time required to close the contacts is very short once the buckling temperature is reached.

A general survey of possible propellants for internal fuses shows that the highest poison velocities are developed by shaped-charge propellants. If the poison were used as the liner of a shaped charge, velocities of 1,970–6,550 ft/sec are possible. Preliminary firings with dynamite indicate that this idea has possibilities as part of a very fast-acting fuse; further tests have been conducted using the explosive C-3. The blast associated with the high-explosive action is a great disadvantage, but it can be reduced by using a blast brake or by firing the shaped charge down an evacuated tube.

Tests with a "shotgun"-type propellant system showed that poison may be shot into a reactor in less than 5 msec, and possibly in 1 msec. The blast from such a "shotgun" should not be great enough to do an objectional amount of damage (APEX-397 Oct. 1953).

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Scanning the Literature

Hydrodynamic- and hydrostatic-lubricated bearings. This survey concludes that there is sufficient data available, references to which are listed, to provide an experimental application of a hydrostatic system for selected bearing applications. (APEX-390; $1.00*)

Merchant-ship propulsion. A bibliography (978 references) covering various phases of the application of nuclear power to merchant-ship propulsion is arranged in the following subject groups: ship characteristics; main and auxiliary machinery; reactor types; reactor-design information; health physics and waste disposal; economics; laws and regulations. (ASAE-S-10; $2.50*)

Two-phase heat transfer. A review of single- and double-component heat transfer in two-phase gas-liquid mixtures flowing in vertical and horizontal tubes under natural and forced circulation has sections covering the effects of agitation and surface on nucleate boiling. (AERE-CE/R-2496; $2.88 from British Information Services, 45 Rockefeller Plaza, New York, N. Y.)

Reactor containment. Primary emphasis is placed on studies of the penetration of steel plate by projectiles in the form of long rods. The problem of deformation of thin plates is formulated theoretically. A theory of deformation energy for large deformations is presented. (AECU-3831*)

Neutron cross sections. This compilation purports to present all the known experimental data for total and reaction neutron cross sections for all isotopes in the energy range 0.001–14.5 Mev. (UCRL-5226; Part I Vol. I and II $6.00, Vol. III $4.00*)

Plutonium-recycle reactors. A generalized formulation of material and reactivity balance in plutonium-recycle systems is developed and coded for the IBM-650. Steady-state operation and linearly graded irradiation are assumed. Isotope-concentration equations are linearized by using effective reactor cross sections. (HW-54074; $1.00*)

Thermal conductivity and viscosity of gases. Properties of He, A, N, O, CO_2, CH_4, C_2H_4, C_3H_8, methyl ether, and methyl formate and selected binary and ternary mixtures of them were measured in a concentric silver cylinder cell at 100–540° C. (UCRL-8230*)

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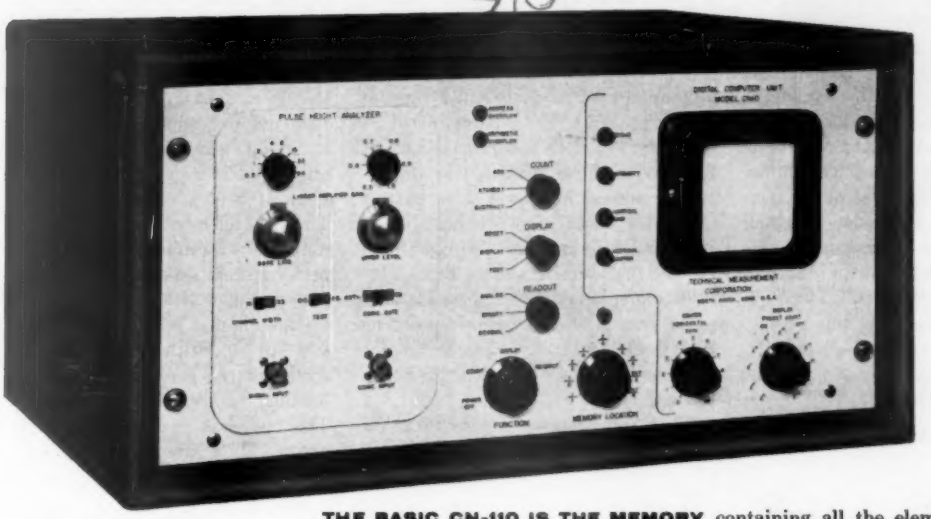

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Fast Oxide Breeder—Fuel Cycle and Cost

By J. K. DAVIDSON,* R. S. MILLER,* and D. J. SMITH
Knolls Atomic Power Laboratory, Schenectady, New York

The fast breeder is of long-range interest because it is based on one of the two fuel systems† that can produce more fissionable material than it uses. An oxide-fuel cycle in a fast breeder is of particular interest, however, because it appears to be possible to arrive at a fuel-cycle cost low enough to make this system of short range interest as well. In other words, it appears that economic power can be produced in a fast reactor system having a UO_2-PuO_2 core in the near future.

For any nuclear power plant to compete with a coal-fired plant, the nuclear system must result in a fuel-cycle cost below that of the coal-fired plant because the capital-equipment investment in the nuclear plant will almost surely be higher than that of the conventional plant. A breeder in which the value of the excess fissionable material is actually a credit, or negative fuel cost, is a good start. The fuel-cycle cost, as defined for this article, is made up of the three components: (a) the nuclear fuel cost, which may be a credit, (b) fixed charges on fuel inventory and (c) fuel processing costs, including fuel-element fabrication and reprocessing.

Because the fuel cost is a credit in the case of a fast breeder, and because the fixed charges on the fuel inventory are quite large but not limiting, it follows that the economic feasibility of a fast reactor system depends almost entirely on the cost of the reprocessing of the fuel.

This last is where the potential advantages of a fast *oxide* breeder appear. The UO_2-PuO_2 fuel is uniquely suited to low processing cost for two principal reasons: (a) the recovery process has fewer steps than is usual for metal fuel elements, and fabrication is relatively simple; and (b) the fuel element should be capable of extremely high burnup because radiation damage should not be a problem, and void space is available in the element for the accumulation of fission gases.

This high burnup results in a low reprocessing rate, which means a small reprocessing plant will be required. Because processing is of prime importance, the development work that has been done has included not only the areas of reactor physics and fuel-element design but also fuel-element handling, chemical reprocessing and fuel-element refabrication.

Reactor Description

The original investigation of the nuclear characteristics of oxide-fueled fast reactors was carried out by Luebke and Sampson (*1–3*). We will consider a sodium-cooled, two-region reactor having a right cylindrical core. Fuel elements are stainless-steel tubes ~0.2 in. in i.d. and 42 in. long containing mixed dioxides of plutonium and uranium at ~65% of theoretical density. This fuel element, and the MTR irradiation experiments that have been performed on small test sections of it, have previously been described (*4, 5*).

The nominal power level assumed is 800 Mw(th), with ~660 Mw(th) generated in the core region and the remaining generated in the blanket. The temperature rise through the reactor will be about 300° F and the

---

* Present Address: Nuclear Products—Erco Div., ACF Industries, Inc., Washington, D. C.

† The other is the thermal reactor with a Th-U^{233} cycle.

TABLE 1—Processing-Plant Investment

Major process equipment, delivered	$ 314,210	
Major process equipment, installed	439,890	$ 439,890
Instruments, delivered	28,750	
Instruments, installed	47,440	47,440
Process piping	188,530	188,530
Nonmanufacturing capital investments		
Building estimate (includes manipulators)	842,830	
Auxiliary estimate	314,210	
Delivered cost of spares	108,300	
	$1,265,340	1,265,340
Total physical cost		$1,941,200
Plant construction overhead		776,480
Total plant investment before startup		$2,717,680
Startup		271,770
Total plant investment		$2,989,450

TABLE 2—Annual Operating Cost

Raw materials	$ 50,000	$ 50,000
Direct labor	203,000	203,000
Process utilities	63,000	
Maintenance	111,270	
Supplies	9,470	
Supervision and clerical	50,750	
Property taxes and insurance	89,680	
Laboratory	50,750	
Employee benefits, etc.	46,410	
Miscellaneous plant overhead	224,690	
	$646,020	646,020
Depreciation		298,950
Shop cost		$1,197,970
Manufacturing cost		1,257,870
Waste storage		50,000
Profit before taxes		326,160
Annual operating cost		$1,634,030

average outlet temperature will be about 1,000° F. Heat will be transferred from the primary coolant to a secondary liquid-metal coolant and from the secondary coolant to superheated steam and boiling water. The over-all thermal efficiency from reactor heat to electrical power should be over 30% using standard reheat practice.

Economic Analysis

The approach taken in the economic studies for the Fast Oxide Breeder is a very much simplified approach. We assume that the annual cost of the reactor and its steam plant, excluding the fuel-cycle cost, will not be larger than the total cost of a conventional plant. Although this is a big assumption, it is at least as reliable a basis for comparison as detailed cost estimates of the reactor plants that take much more effort to prepare.

In making cost comparisons of this type, the only capital-investment cost that must be estimated is the cost of the reprocessing plant. Because this is the area in which considerable development has been done on the oxide breeder system, the reliability of these comparisons should be relatively high. Table 1 shows, in summary, the capital cost estimate (*6*) for the processing plant. Table 2 gives the estimated operating cost for this same facility. Table 3 shows the total fuel-cycle cost for the oxide breeder, which has been estimated from the previous operating cost for the plant, shipping-cost estimates, estimated costs for processing the blanket material and inventory charges on the fissionable material in the processing plant and reactor. The total cost, with no credit taken for the plutonium bred, is seen to be about 2 mills/kwh. If a credit is taken for the breeding gain at the rate of $12/gm (the published cost for low-grade plutonium), the net fuel-cycle cost becomes approximately 1.5 mills/kwh. Thus, if the total fixed charges and operating costs for the reactor and steam plant were to amount to 5–7 mills/kwh, the total cost of power produced by this system would be competitive in many parts of the United States.

Fuel-Cycle Development

The spent fuel from this reactor will still contain 50% of the *original* plutonium but will, nevertheless, contain approximately three quarters as much total plutonium as it originally had, because of breeding Pu from U^{238}. Thus, reprocessing is an inescapable part of the economics of such a reactor system. This is true, in general, of any fast reactor system because of the high enrichment of the fuel. The fuel cycle that has been adopted is that of a fuel-processing plant integral with the reactor. The fuel cycle is shown in Fig. 1. Throughput of core and blanket materials for the system operating at 800 Mw(th) for 300 days per year is as shown in Table 4. The cycle and its equipment are described in the following paragraphs.

After they have cooled in storage,

TABLE 3—Annual Fuel-Cycle Cost

		($/yr)	(mills/kwh)
Inventory charge—50 tons natural U at $40/kg plus 600 kg Pu at $12/gm (at 6%)		552,000	
Core cost (processing cost plus $400,000 for fabrication)		2,034,030	
Blanket cost—23.75 tons natural U			
Shipping	at $ 5/kg		
Processing	at $25/kg		
Fabrication	at $10/kg		
	$40/kg	950,000	
Gross fuel-cycle cost		3,536,030	2.04*
Credit for Pu breeding gain (assume breeding gain is 0.3 and $12/gm for Pu)		890,000	0.51
Net fuel cycle cost		2,646,030	1.53

* $\frac{\text{mills}}{\text{kwh}} = \frac{\$/\text{yr}}{1.73 \times 10^6 \text{ kwh/yr}}$

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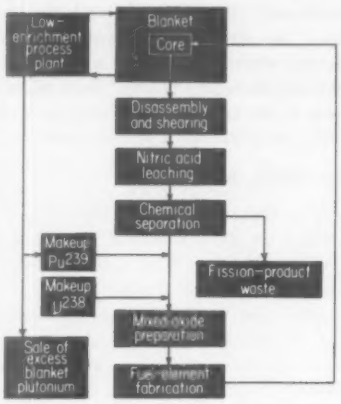

FIG. 1. Fuel cycle for Fast Oxide Breeder. Recovery process has fewer steps than usual metal-fuel-element process

the fuel-element sub-assemblies are taken apart and the individual rods are mechanically sheared into short sections from which the spent fuel is leached by nitric acid. Spent reactor fuels that can be leached from their cladding material permit a great reduction in the size and complexity of the processing-plant equipment through the elimination of large volumes of inert cladding material in the feed stream.

Experimental equipment has been developed that will shear rods up to ¼ in. in diameter into ½-in. sections with a minimum of crimping of the cladding. The shear consists of a cutting die that moves with a reciprocating motion across a circular hole

TABLE 4—Fuel-Processing Rates*

	Processing rate (kg/day)
Core	
PuO_2	1.36
UO_2	7.88
Fission-product oxides	0.90
Stainless steel	2.24
Blanket	
Uranium	171
Plutonium	0.855
Stainless steel	11.45

* Basis: internal breeding ratio is 0.5; external breeding ratio is 0.9; blanket material removed at 5,000 gm Pu/ton of U; reactor operates 300 days per year; plant operates 250 days per year.

in the face of the die plate. A number of simulated fuel elements, made by swaging stainless-steel tubing over sintered alumina rod, have been used for testing the equipment. These tests show that deformation of the cladding and chipping of the fuel at the point of sectioning is not excessive at operating rates up to 75 cycles per minute.

A conceptual design has been prepared for a rotating shear that can be used in the ceiling of the hot cell. This unit, shown in Fig. 2, consists of a revolving magazine loaded with fuel elements and a shear that will section all of the fuel elements in the magazine as they are expelled through the bottom of the unit. The sheared fuel falls by gravity into a critically safe dissolver that is provided with a basket

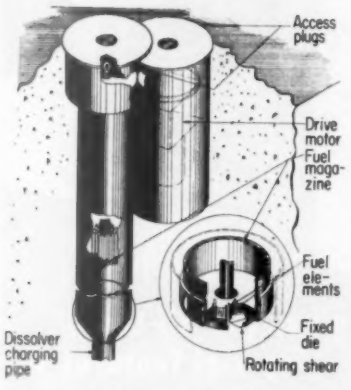

FIG. 2. Fuel-element shearing mechanism conceptual design

for removing the sheared, leached cladding sections.

A critically safe dissolver (see Fig. 3) has been constructed and operated to demonstrate the mechanical features and hydraulic operation of such a system. It consists of two vertical 8-ft sections of standard 6-in. pipe located on 2-ft centers. These two legs are interconnected by horizontal sections of 1½-in. pipe at the bottom, middle and a point above the liquid level. A downdraft condenser is located in the top portion of one vertical leg; the other leg is left clear for the removal and replacement of the basket. A disposal cask, constructed so that it can be lowered over the leg containing the basket, is used to seal the open top of the dissolver as well as for cladding disposal.

Simplicity of chemical dissolution is one of the advantages of the UO_2-PuO_2

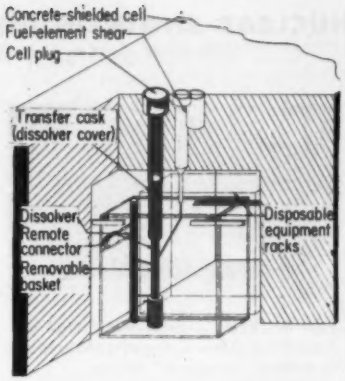

FIG. 3. Critically safe dissolver arrangement. Overhead crane not shown. Access for liquid lines to cell is provided through remote-disconnect flanges

fuel. It is well known that ignited PuO_2 goes into solution only with difficulty, even in HNO_3-HF mixtures, but UO_2 is readily soluble in concentrated nitric acid. It was hoped that, if the two oxides were obtained in the mixed crystal form, the PuO_2 dissolution problem would not be severe. Samples of the mixed dioxide have dissolved easily in hot nitric acid both before and after irradiation. A simple dilution of the dissolver liquor will yield a solution meeting the specification for the feed stream in the modified Purex-type solvent-extraction flowsheet that is used for fission-product decontamination.

The equipment that has been discussed up to this point will require at least 3½ ft of 4.5-density concrete shielding, but savings can be realized with a throw-away replacement scheme; i.e., by not allowing entry to the cell for maintenance, it is necessary to shield a minimum volume of equipment only. Provision is made for equipment disposal by mounting it on a series of three racks within the cell. Each rack travels on a set of overhead rails.

A remote-disconnect flange for connecting tubing through the cell wall to equipment located on the disposal rack has been developed (see Fig. 4). The connector utilizes Swagelok fittings compressed between two stainless-steel mounting blocks with a clamping bolt. The assembly, which can be operated remotely from the outer cell face, replaces the regular fitting nuts of the individual connectors. This method of construction provides a gasketless, leakproof connection having only stainless-steel parts—a feature that is

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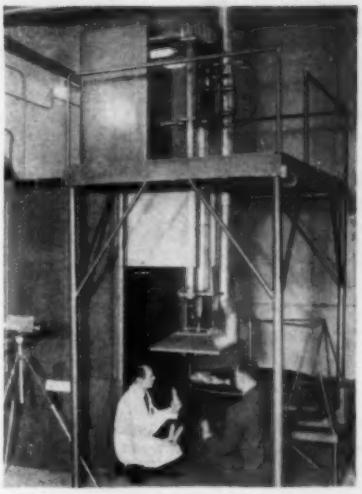

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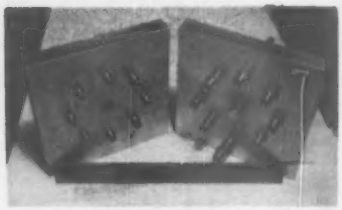

FIG. 4. Remote-disconnect flange disassembled shows both parts of standard Crawford "Swagelok" fittings

particularly advantageous in handling corrosive, radioactive solutions.

The partially decontaminated fuel from the solvent extraction step is recovered by precipitation, filtration, drying and firing steps. It is then extruded, sintered and loaded into stainless-steel tubing to form the reconstructed fuel elements. It is necessary, because of the residual contamination in the fuel after solvent extraction, to handle the refabrication process remotely. To this end, use has been made of a rotary-drum vacuum filter and a revolving barrel extruder (see Fig. 5).

The blanket elements are not processed at the reactor site but are shipped to a centralized processing plant for low-enrichment materials. The high-quality plutonium in them is extracted, a portion is returned to the reactor and the remainder sold. This duplex fuel cycle is felt to be optimum because the core fuel is unique, of high unit value, and must be processed as a special problem. The blanket material is of low unit value, is very similar to

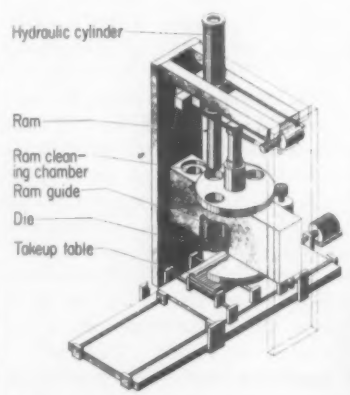

FIG. 5. Revolving-barrel extruder conceptual design

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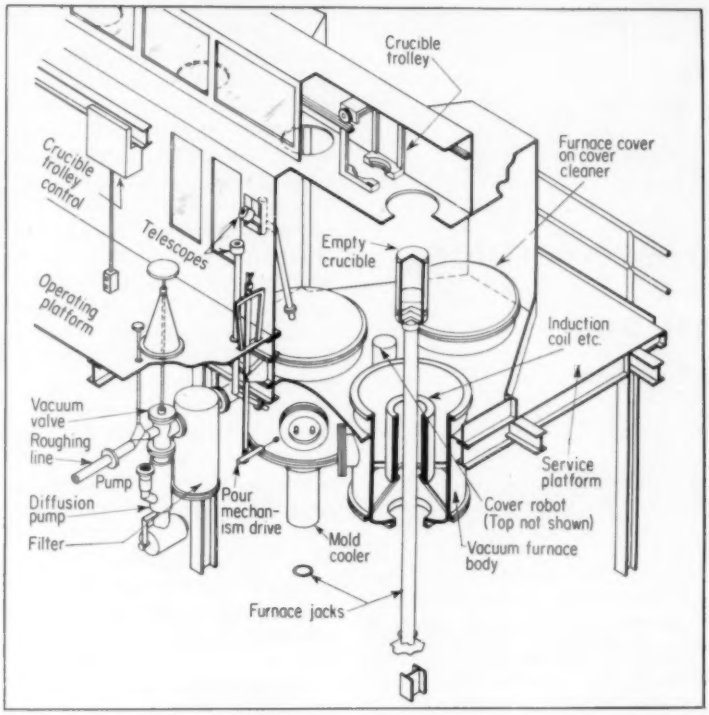

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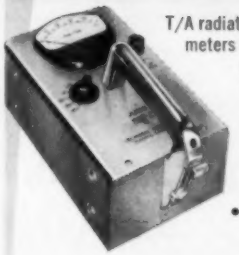

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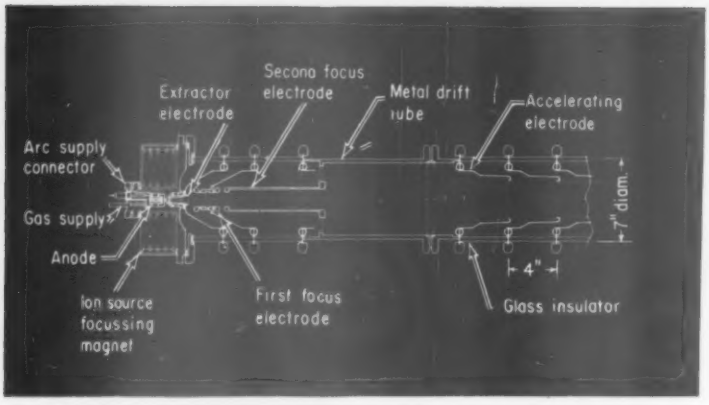

FIG. 1. Ion source, focusing electrodes and drift-tube assembly of University of Arkansas Cockcroft-Walton accelerator

High-Current, 400-kv Cockcroft-Walton Accelerator

By W. L. BRONNER, K. W. EHLERS, W. W. EUKEL, H. S. GORDON, R. C. MARKER, F. VOELKER
Applied Radiation Corporation, Walnut Creek, California
and R. W. FINK
Department of Chemistry, University of Arkansas, Fayetteville, Arkansas

A 400-kv Cockcroft-Walton accelerator capable of delivering 2-ma ion beams with hydrogen isotopes has been installed in the University chemistry department (*1*). Target techniques have provided neutron yields of 10^{11}–10^{12} DT neutrons/sec (14.8 Mev at 0 deg to the beam axis) and 7×10^8 DD neutrons/sec (2.95 Mev at 0 deg).

Ion Source

The ion source is of the cold-cathode, high-voltage-arc type with axial magnetic field and was designed to operate continuously. To minimize the input power and cooling requirements as well as inlet gas flow, a source embodying the efficient Penning (*2*) or Phillips ion-gage type of discharge was designed. In addition to efficiency, this design does not require heated cathodes, and its associated electronics are simple power supplies.

In this type of ion source (Fig. 1), the two cathodes are electrically connected, and the anode is positive with respect to both. Initially, electrons present in the gas or released from either cathode are accelerated into the arc chamber and reflected by the opposing cathode. These electrons, whose radial motion is restricted by the solenoidal magnetic field, give up their energy by ionizing the gas that has been admitted to the chamber. Ions produced by these axially oscillating electrons strike the cathodes and release secondary electrons, which are returned to regenerate the cycle. This action produces an intense arc plasma from which ions are extracted through a hole in one cathode.

The source operates at a pressure of ~20 microns and a gas flow rate of about 25 cm³ (NTP) per hour. The effective voltage across the source during normal operation is approximately 800–1,500 volts with an arc current of 12–25 ma. Aluminum cathodes are used. In addition to their high sputtering threshold (*3*), the cathodes are easily replaced and have an operating life in excess of 250 hr at a beam current of 1,500 μa.

Outputs in excess of 1.8 ma can be focused to a 1.2-mm-diameter spot at the target, 3 meters away from the ion source. The ratio of molecular ions to atomic ions is roughly 1 to 1 as determined by work previously done with this source type (*4*). Present plans are to measure this ratio under various conditions with an analyzing magnet. Gases other than hydrogen or deuterium, such as argon, helium, nitrogen, oxygen, etc., can be used with this source without any changes.

Target Techniques

A diagram of the target plate is shown in Fig. 2. Methanol refrigerant at −15° C is circulated through the grooves within the target plate. Up to about 600 watts/cm² can be dissipated without exceeding 100° C. Transmission of the plate for DT neutrons is >97% and >85% for DD neutrons. Liquid nitrogen can be used for extreme cooling.

Tritium-saturated evaporated zirconium targets* on thin platinum backings 3.2 cm in diameter are indium-soldered (165° C) to the copper-clad aluminum† target plate. The target generally used is one in which the superficial density of the zirconium lies between 200 and 500 μg/cm² over the entire 3.2-cm diameter. Approximately 1.4 curies of tritium absorbed in a 300-μg/cm² 3.2-cm-diameter zirconium target gives a T:Zr atom ratio better than 1.4:1.

Such targets exhibited, under bombardment with 700 μa at 400 kv of defocused beam containing approximately equal numbers of D_2^+ and D^+ ions,

* Obtained from Oak Ridge National Laboratory, Oak Ridge, Tenn. Information on the preparation of Zr-T targets has been summarized by Massey (*5*) and Arrol et al. (*6*).

† "Alcuplate" type 10/80/10 obtained from General Plate Div., Metals & Controls Corp., Attleboro, Mass.

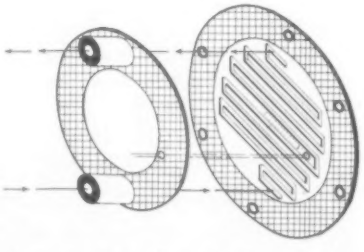

FIG. 2. Internal construction of refrigerated target plate. Grooves are for circulation of coolant

continuous DT yields as high as 10^{11}–10^{12} neutrons/sec at a target temperature not exceeding 50° C. A continuous total yield of 4×10^{10} neutrons/sec produces a useful maximum flux of about 2.4×10^{9} DT neutrons/cm²/sec passing through thin copper monitor foils [$Cu^{63}(n,2n)Cu^{62}$] placed in contact with the atmospheric side of the target plate.

Preliminary experiments have been carried out on the DD neutron yield obtained by bombarding silver or gold targets 0.25 mm thick with 400-kv deuterium ions. Typical results are shown in Fig. 3 for a silver target. It is evident that about 88 min are required to achieve saturation‡ with a steady current of 600 μa at 490 kv. At saturation, a total of 3.14×10^{8} DD neutrons/sec were being produced. Interestingly enough, increasing the beam current did not result in an increased neutron yield, either with a defocused or a sharply focused beam even with many hours with currents as high as 1,400 μa at 390 kv§ (target temperature at no time exceeding 100° C).

It has been suggested by C. D. Moak of ORNL that silver might be suitable as a self-regenerating target for the proposed mixed triton-deuteron beam technique because of the white powder formed on the surface. It was thought that as the white powder spalls off, fresh surfaces would be exposed to the beam. This would eliminate trouble with carbonaceous deposits and permit a much greater beam current to be laid on, because there would be less danger from target overheating and cooling could be made more effective by circulating Freon directly against the back of the silver target. Such a regenerating target might permit DT yields as high as 10^{12}–10^{13} neutrons/sec to be achieved with mixed beams of up to 10 ma at 400 kv (upper limit of present machine, without modification, is 2 ma). From our preliminary results with the DD reaction on silver and gold, we conclude that these elements probably will not

‡ In agreement with the finding of K. Fiebiger (7) for very low beam current of 50 μa at 300 kv. Fiebiger studied the DD yield vs duration of irradiation at constant beam on fresh targets of Al, Ag, Au, Cr, Cu, Fe, Ir, Mo, Ni, Pd, Pt, Ta, Ti, W, Zr and graphite. The highest yield was observed from gold targets, which exhibited a saturation yield of about half that obtained from D_2O ice targets.

§ In one experiment, a beam of 1,800 μa at 380 kv caused melting and sputtering of the silver target.

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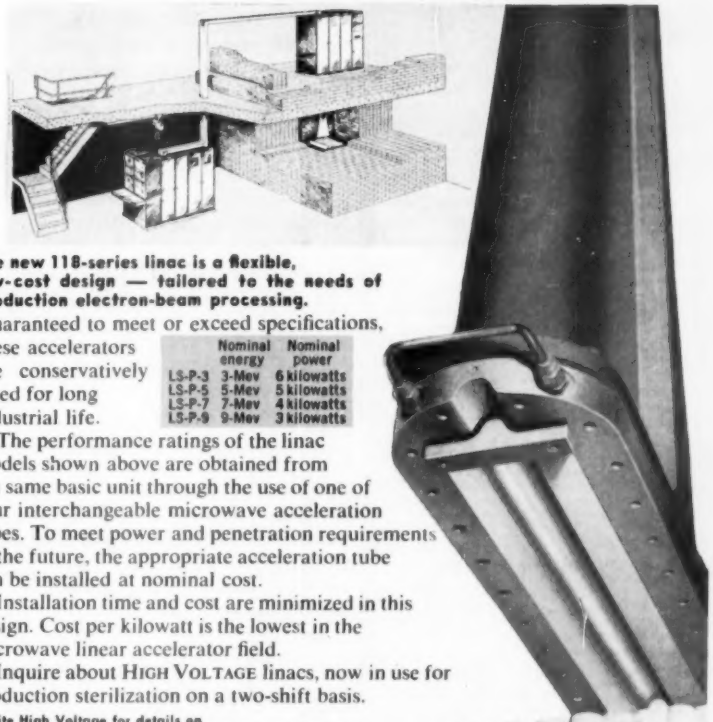

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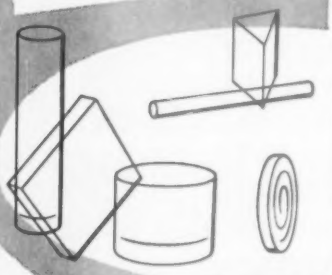

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prove to be promising targets for this purpose.

Fiebiger (*6*) has shown gold to be the most effective self-regenerating target for the DD reaction. In an experiment identical to the one described for silver targets, we found the DD yields from gold were practically identical to those obtained from silver targets with beams of 600–1,400 μa at 400 kv. This contrasts strongly with Fiebiger's data (*6*) for low beam currents (50 μa at 300 kv).

The DD (2.95 Mev) neutron yield also was measured from a zirconium-deuterium target of the same type as described earlier for zirconium-tritium. The yield from this target was more than double that from either the silver or the gold self-regenerating targets. With a 520-μa, 400-kv deuterium ion beam (defocused), a sustained total yield of 7×10^8 DD neutrons/sec was produced.

The white powder of previously unknown identity that forms under prolonged deuteron bombardment (10,000 μa-hr) of silver targets was examined in situ by X-ray diffraction by R. F. Kruh of the chemistry department. The scattering pattern could be interpreted as being due to crystalline silver. No lines other than those of silver were observed. A comparison of the diffraction pattern of unirradiated silver with that of the silver target having the white powder on its surface showed that the former had broad, diffuse lines, whereas those of the latter appeared to be much sharper and in some lines actually spotty. This indicates that, although the original silver was extremely fine-grained, the white powder exhibited a rather large increase in microcrystalline size, as evidenced especially by the spotty nature of the diffraction lines.

High-Voltage Supply

The high voltage for the accelerator is provided by a Cockcroft-Walton cascade rectifier. To provide flexibility of design, the supply is built in two-stage Lucite decks, which are stacked on top of each other. The Arkansas supply is of open nonpressurized construction, ten decks high, and provides mechanical support for the high-voltage terminal.

Each deck uses eight 10-kv, 5-ma IRC selenium rectifier cartridges of 250 cells each to provide a basic rating of 40 kv per deck. There are four GEO 25-μf, 20-kv Pyranol capacitors per deck. The 10 decks provide up to 400 kv. Up to 50 kv of additional beam energy is available from the ion-source focus supplies.

Although this is basically a continuous 400-kv, 3-ma supply, there is sufficient filtering capacity to provide a 100-ampere, 1-μsec pulse with only 1% drop. The supply can provide either positive or negative voltage by reversing the rectifier cartridges.

Vacuum System

The vacuum system consists of an MCF 300 diffusion pump (100 liters/sec rated speed at 10^{-6}-mm Hg) backed by an NRC 4D mechanical pump, having a capacity of 1.5 liters/sec at a measured forepump pressure of 5×10^{-4} mm. A water baffle and two refrigerated optical baffles (−65° C) using Freon-22 are located above the diffusion pump to trap out backstreaming oil vapors.

Typical vacuum measured at the ground end of the accelerator tube with

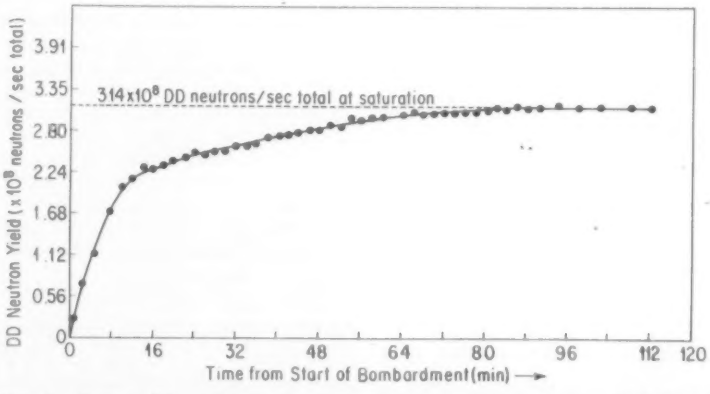

FIG. 3. Typical DD neutron yield from 0.25-mm-thick silver target. Gold-target results are almost identical in time to reach saturation and in magnitude of neutron yield

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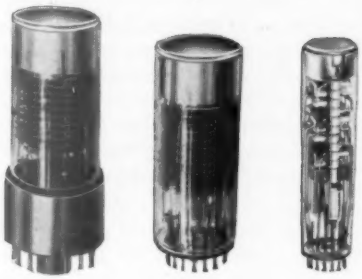

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The pole faces are equipped with removable shims to permit double-focusing of the deflected ion beam. The vacuum envelope is constructed of aluminum and has five output ports, arranged at 0 deg and at 10 and 25 deg to the right and left of the beam center line. These permit multiple experimental setups and rapid switching of the beam from one target to another.

* * *

This work was supported in part by the U. S. Atomic Energy Commission. For a more detailed report, see AEC report ORO-172, March 1, 1958.

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TECHNICAL BRIEF

Planchet seal. N. Irving Sax and David Rosi of the radiological laboratories of the New York State Department of Health have developed a radioactivity-counting-planchet seal that shows no sign of opening after four months.

"Saran Wrap" can be bonded to metal, glass or plastic very simply. The planchet is covered with the Saran, and the ends are twisted tightly underneath to provide a taut film over the face of the planchet. The area of the plastic to be sealed to the planchet is then rotated in a gentle flow of steam for ½ min. After cooling, the excess Saran is trimmed away with a razor blade.

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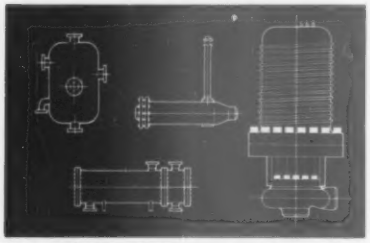

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APPLIED RADIATION

Faster Pipe-Weld Testing Uses Ir^{192}

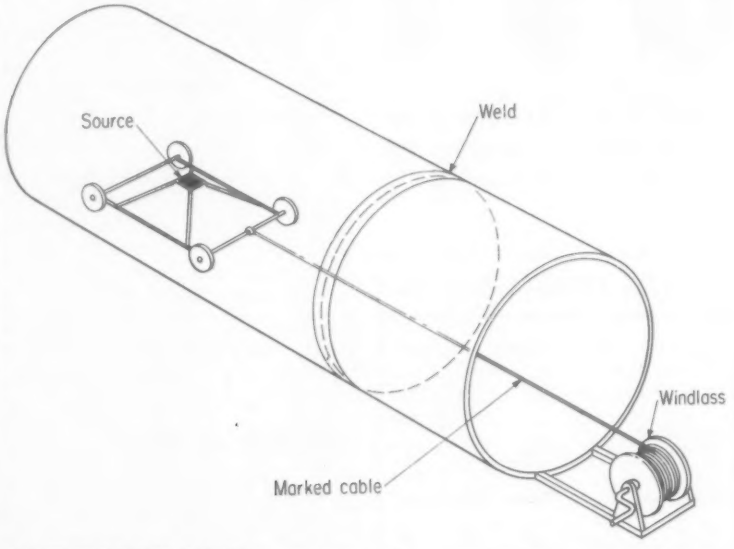
Pipeline radiographers in Germany are now prepared to inspect welds faster than they can be made. With a gamma-ray source on the axis of 24-in. and 28-in. pipes they can inspect up to 100 welds a day using 1-min exposures.

Two large pipelines have been inspected during their construction. One is the 28-in. 220-mile one from Wilhelmshaven to Cologne. The second connects Rotterdam and the Rhine. It is 24-in. in diameter and 185 miles long. Gelsenberg Benzin A. G. developed the method for their own use, and it is now being employed by Fritz H. Gottfeld, Cologne, as independent test laboratory to Deutsche Oelleitung, Hamburg, builder and operator of the Wilhelmshaven-Cologne line.

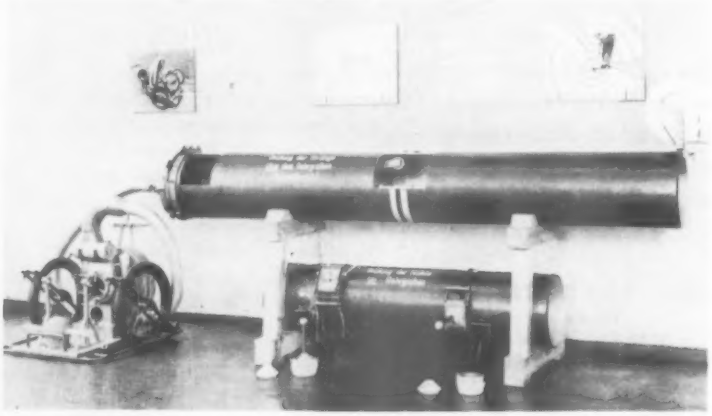
Radiographic source for the inspection is up to 18.5 curies of 74-day Ir^{192}. An 0.086 × 0.110-in. cylinder is encapsulated in a $\frac{5}{64}$-in.-thick steel tube with lead plugs at its ends. The source remains usable through about two half-lives.

Forty-foot lengths of pipe are checked hydrostatically at the factory and their longitudinal seams are now inspected by ultrasonics instead of using the earlier X-ray examination. In the field, 12 or 13 of these lengths are welded together, and sections of this size are inspected as shown in the sketch in Fig. 1.

The source is mounted on a wheeled carrier so that it moves along the axis of the pipe. Markings on the cable attached to the carrier tell the operators when



WHEELED SOURCE CARRIER moves through pipe. Marks on cable show position so that source can be stopped opposite welds **Fig. 1**



LATER METHOD uses pneumatic movement. Lower display shows saddle for holding source outside weld **Fig. 2**

to stop so that the source is opposite the weld to be inspected. Strips of Gevaert Structurix D-7 film are laid around the weld outside the pipe. Pipe thickness is $\frac{5}{16}$ to $\frac{7}{16}$ in., and the welds add $\frac{3}{64}$ in. to this thickness.

Pneumatic movement has been substituted in later inspections for the winch-and-cable action shown in the sketch. The new equipment is shown in Fig. 2. One end of the pipe is plugged, and a pipe-filling diaphragm is fitted to the source carrier. The cable is still used to judge the position of the source, but nowadays it is marked by laying it along the top of the pipe. Formerly it was necessary for some one to crawl through the pipe pulling the cable and reporting his position to a marker man outside.

Welds that connect the longer sections, the so-called 'tie-in' welds, must be radiographed with the source outside the pipe. A special source-holding saddle (Fig. 2) makes this possible. It is strapped round the weld and held against the pipe by two strong magnets. A conical depression is available in the saddle, and into it fits a special 8½-lb. source holder. This is shown in Fig. 3.

FOR EXTERNAL EXPOSURES this source holder fits in saddle Fig. 3

A bayonet fastening holds the source in place. Removable shielding protects the source for carrying. A worker carrying the unshielded source is safe from exposure if he points the source away from himself and holds it at arm's length.

Up to now, a total of about 60,000 radiographs over the greater part of the Wilhelmshaven-Cologne pipeline have been made in addition to the standard ultrasonic testing at most of the tie-in welds.

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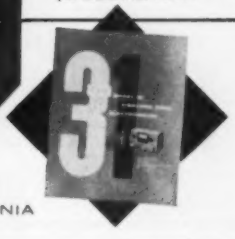

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THERMONUCLEONICS

Fusion-USSR: How They Do It

The Russian effort in the field of controlled thermonuclear power is to be respected, as the world learned at Geneva and in subsequent contacts with the hitherto secret fusion laboratories of the USSR. Leader among the Russian fusion laboratories is that at Kurchatov's Institute of Atomic Energy in Moscow. L. A. Artsimovich is directly in charge of the experimental work, which is concentrated on pinch devices but includes Joffe's ion magnetron and Ogra (NU, Sept. '58, 23). In addition there are vigorous groups at Kharkov, Sukkumi and Leningrad; and one (under G. I. Budker) is planned for the projected Siberian Institute of Physics near Norosivirsk.

Britain's Sir John Cockcroft, most recent Western visitor to the Moscow thermonuclear labs, reports their fusion effort to be extremely well coordinated, and about three times the size of the British program, or roughly the size of the American program. In his opinion the Russian program covers a narrower front than that mounted in the U. S. A. They have an ample supply of physicists and mathematicians and their equipment is superb. He does not think the quality of their scientists any better than in Britain. Their morale is high and their enthusiasm much the same as any group of Harwell, and they were organized on a much less formal basis than at Harwell.

There was abounding evidence of the superb quality of their mechanical and electrical engineering. Cockcroft instanced the building of Alpha, a copy of the British ZETA apparatus, in only six months after the general details had been made public in January this year. Alpha is now operating. OGRA, at the Moscow Institute of Atomic Energy also was built in six months. In a NUCLEONICS interview, Cockcroft implied these projects represented two years of work on Western standards, after issue of drawings. [NUCLEONICS learned that Harwell photographs proved conclusively that the Russian Alpha thermonuclear apparatus was based on ZETA. Details that appeared in the Harwell pictures published last January (NU, Feb. '58, p. 90) are faithfully reproduced in the Russian Alpha apparatus. The only details that show original treatment are those which are known never to have appeared in a Harwell picture].

The astonishing rate at which it was built is largely attributed to the novel set-up at the Electro-Technical Institute in Leningrad. At this Institute the Russians have centralized the design and manufacture of all novel electrical equipment and other highly specialized scientific apparatus. Under its roof they have developed a generation of engineers capable of handling scientific projects unprecedented in their scale and novelty. Many of its staff did a three-year physics course before starting their engineering training. Uninhibited by outmoded professional standards of the West this aristocratic design group has mastered the art of building temporary experimental apparatus on a large scale. Over-all appearance is unimportant, component surfaces and finish ignored. Long life is not neglected—it's simply designed out.

Backing up this Panzer division of non-textbook engineering experts there is a lavish deployment of experimental research equipment and large modern manufacturing facilities. Once there these men stop there, which assures an enviable continuity of effort. And with design development and manufacture centered under one roof, scientists, engineers and production experts enjoy unrivalled liaison opportunities.

Compared with this set up, British and American scientists are hamstrung NUCLEONICS was told. One-shot contracts with large research content have to be let to companies whose design personnel are largely engaged in more lucrative commercial operations. Designers forced to stick with long antiquated commercial design requirements in the interests of professional standards overprovide for component life and quality.

Apparatus is painted, smoothed, and polished because company reputations must be safeguarded. The Russians have none of this to contend with.

But if some time saving factors in the Russian setup possess merit others have sickening implications. According to reliable AEA sources the Russians are seriously neglecting safety factors in order to by-pass shielding delays. A certain disregard for accepted radiation hazards was evident everywhere in the Russian nuclear establishment. "What's a little radiation sickness compared with 12 months off the development time of a nuclear project."

BOOKS

Radiation Protection

By CARL B. BRAESTRUP and HAROLD O. WYCKOFF (Charles C Thomas, Springfield, Ill., $10.50, xix + 361 pages, 1958).

Reviewed by L. D. MARINELLI, Argonne National Laboratory, Lemont, Ill.

Radiation protection is quite an extensive field nowadays; it ranges from the avowed influence of natural radioactivity on the life span of man to the more tangible hazard of automatic X-ray inspection of fluid level in beer cans, and it covers *pari passu* the monumental procedures of radiation control in nuclear power plants as well as the plain advisability of restricting the consumption of Brazilian nuts.

In a situation as varied as this, with so many detailed questions to answer while decisive knowledge is still lacking, it is comforting and refreshing to witness the appearance of a sensible book based on a minimal amount of avant-garde speculations and obviously not guided by the interest of profiting from unfounded fears.

By avoiding the amply covered specialty of nuclear reactors, the authors manage, in the rather limited space of some 350 pages, to offer a general radiation protection guide to the engineer, the architect and the scientist. It is a book written by well known specialists for the nonspecialist professional who needs acquaintance and guidance in this field.

Besides the technical details contained in eleven chapters and eight appendices, this volume offers an excellent foreword by L. S. Taylor and an introduction by the authors, which should be required reading for any layman who desires to discuss the matter with a modicum of sense.

The physics of radiation and its measurement are succinctly treated in about fifty pages supported in turn by a bibliography, which, though not exhaustive, is adequate to lead the inquisitive reader through the proper channels. The history of radiation protection and a description of the recognized injurious effects of radiation are summarized in thirty pages by T. C. Evans and S. A. Lough. These authors, very wisely, have refrained from extemporizing on details that are the source of so much controversy and have confined their bibliography to key references. This reviewer found particularly amusing, on p. 72, T. C. Evans and S. A. Lough (biologist and biochemist, respectively) quoting R. D. Evans (physicist) on interpretation of biological effects.

The next chapters on *Shielding Methods and Materials* are an instructive guide for the architect and the engineer confronted with constructional designs of various radiation barriers. The general principles contained therein are ably developed in the next three chapters, which deal also with operational procedures of medical and industrial X-ray installations, ranging from television tubes to betatrons. The didactic scope of these chapters is well supported by discussions of cases encountered in actual practice. Most missed, however, is the lack of bibliography on nonmedical installations.

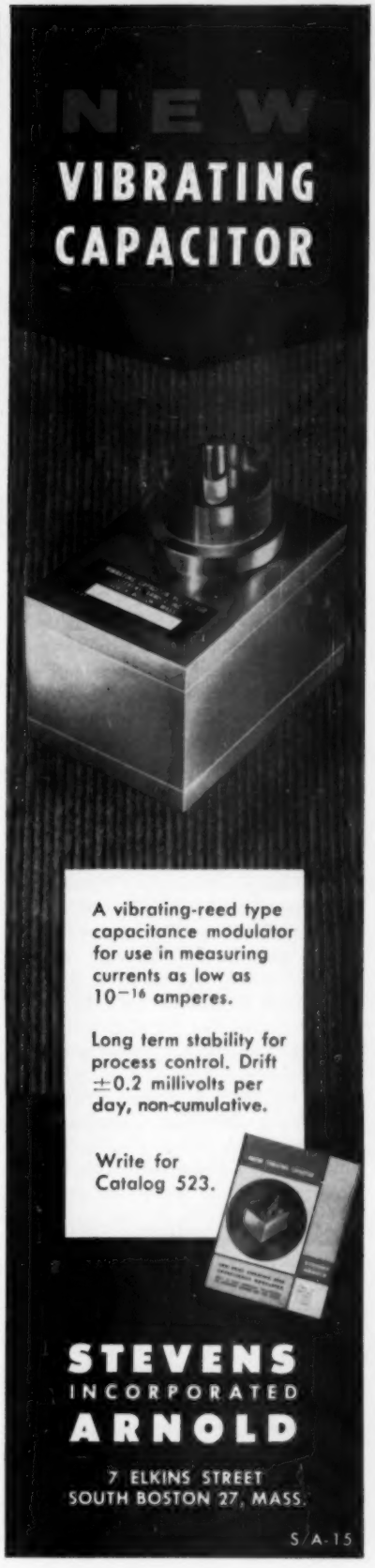
Chapter 9 covers all sealed radioactive sources, irrespective of their use in teletherapy, intracavitary therapy or industrial radiography. Nonsealed sources are discussed by S. A. Lough in the next chapter as they are used in medicine and in industry.

Chapter 11 on atmospheric contamination is by M. Eisenbud, who has leaned rather heavily, but incompletely, on physiological information at the expense of guidance in the practical applications in this very important field. The reason for this unbalance may be found, perhaps, in his discussion of surface contamination.

The last chapter, on radiation surveys, personnel monitoring and supervision epitomizes the administrative obligations to be discharged wherever radiation is employed. Excellent is the section on reports of protection surveys.

The appendices amply illustrate the care with which basic data have been assembled and presented. The last one, entitled *Radiation Injuries, Real and Imaginary*, is unique in wisdom of context; it also gives explicit warning of the abuses that may arise in the future if the effects of radiation on man are not better understood and if the rising trend in "compensation costs" continues unabated.

This book should find wide use in schools, hospitals and industrial enterprises. Few suggestions have arisen in the mind of this reviewer, besides the ones mentioned above, i.e., (a) better index references to accidents of various nature (for instance, radioactive spills are discussed in pages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261–262 but are not mentioned in the index, and (b) better coverage of references to administrative responsibilities; these are spelled out quite thoroughly in the various NBS handbooks issued by the NCRP.

Advances in Biological and Medical Physics

Edited by JOHN H. LAWRENCE and CORNELIUS A. TOBIAS (Academic Press, New York, $12.00, x + 488 pages, 1957).

Reviewed by ROBERT E. ROWLAND, Argonne National Laboratory, Lemont, Ill.

The editorial form of this book and, indeed, the form of the entire series of which this is the fifth volume, is most pleasing. Each of the eleven articles introduces the reader to its subject matter with a brief historical review, then summarizes the progress to date and indicates some of the unsolved problems in the field. The most appealing feature is the fact that these articles are not simply extensive reviews of the recent literature, but are rather authoritative summarizations of the status of the work under consideration. To the biologist, physicist or biophysicist interested in the potential application of these techniques to his work, or interested simply in following the progress in these fields, this book is highly recommended.

The subjects treated are *Nuclear and Electron Paramagnetic Resonance and Its Application to Biology*, by P. B. Sogo and B. M. Tolbert; *Action Spectroscopy*, by R. Setlow; *The Genetics of Somatic Mammalian Cells*, by T. T. Puck; *Partial-Cell Irradiation*, by R. E. Zirkle; *Electrical Properties of Tissue and Cell Suspensions*, by H. P. Schwan; *Quantum Effects in Human Vision*, by A. Rose; *Television Techniques in Biology and Medicine*, by V. K. Zworykin; *Studies Directed Toward the Use of Antibodies as Carriers of Radioactivity for Therapy*, by W. F. Bale and I. L. Spar; *Studies on Exogenous Cholesterol Metabolism in Human Atherosclerosis with the Aid of Isotopes*, by M. W. Giggs; *The Development and Applications of Low Level Counting*, by E. C. Anderson and W. F. Libby; *Radioactivity of the Human Body*, by F. W. Spiers and P. R. J. Burch.

In the light of international discussion on the effect of fallout, the last two articles are timely. Anderson and Libby, stating that "It seems agreed that the natural levels of radioactivity with which man has developed and now lives are 'tolerable'; at least it has not yet been proposed to abolish them." . . . go on to discuss the techniques involved in counting natural radioactive levels. C^{14} and H^3 are discussed specifically at natural levels, while Sr^{90} and Cs^{137} are discussed as examples of fission activity important in people and food.

Spiers and Burch discuss the new and very important field of the measurement of natural levels of radioactivity in the human being. They compare the various techniques employed in laboratories throughout the world and indicate the strong and weak points of each. Those who have worked with the scintillation method, and know its beautiful energy resolution for gamma rays originating *in vivo*, may feel that the coverage of this very important technique is unnecessarily brief.

The last two sections of this article, dealing with the natural levels of radioactivity in body tissues and the resulting radiation dose to these tissues, will probably be of great interest for some time to come.

This book appears to be remarkably free from typographical errors. A very obvious error appears in the chapter by Anderson and Libby—in Table 5 the dimensions are all incorrectly written. Other than this, the editorial work is well done.

Electromagnetic Isotope Separators and Applications of Electromagnetically Enriched Isotopes

By J. KOCH, R. H. V. M. DAWTON, M. L. SMITH and W. WALCHER (North-Holland Publishing Co., Amsterdam, Interscience Publishers, New York, $7.50, xi + 314 pages, 1958)

Reviewed by C. P. KEIM, Oak Ridge National Laboratory, Oak Ridge, Tenn.

This excellent little volume is a valuable contribution to the recent literature on the electromagnetic separation of isotopes. It consolidates in one place a large variety of information on the subject. Frequent references to over three hundred journal articles and government reports comprise an exceptional bibliography.

It can be said that the idea of the electromagnetic separation of isotopes had its origin in 1919. Large-scale separation of the isotopes of uranium was achieved in 1944. By 1958, practically all known stable isotopes have been enriched by the electromagnetic isotope-separation process.

These achievements have been the result of many investigations on the motion of ions and electrons in electric and magnetic fields. Continued research in this general area will be of great value, e.g., in thermonuclear fusion.

Although the electromagnetic method of isotope separation may not be used again for producing large quantities of isotopes (greater than gram amounts), the versatility of electromagnetic isotope separation will encourage its continued use in providing many different isotopes for nuclear research and other applications. This book will be useful, not only to those engaged in electromagnetic isotope separation, but to those who wish to assess the possibilities of securing separated isotopes for their research.

From the brief attention given to the problems of chemistry and of mass spectrometry, the uninitiated might overlook the large amount of excellent development that has been done in quantitative inorganic chemistry and in mass spectrometry in support of electromagnetic isotope separation. However, detailed procedures on the purification of all isotopes have not been possible in this book and one must be referred to reports listed in the bibliography.

The final section by Professor Walcher constitutes a fitting climax to the discussions in this book. He reviews mass analyzing field systems, high current ion beams and space-charge neutralization in ion beams.

Typographically the book is pleasing in appearance and free from errors. Translations into English have been very well done.

Proceedings of the International Symposium on Isotope Separation

Edited by J. KISTEMAKER, J. BIGELEISEN and A. O. C. NIER (Interscience Publishers, New York, $15.00, xx + 704 pages, 1958).

Reviewed by P. S. BAKER, Oak Ridge National Laboratory, Oak Ridge, Tenn.

The papers presented at the first Symposium on Isotope Separation at Amsterdam in April, 1957, have been assembled and are published in this volume. Most papers are included in their entirety, but a few are presented in abstract form.

The contents are divided into nine sections: (1) Chemical Engineering; (2) Molecular Interactions; (3) Chemical Exchange; (4) Electromigration;

(5) Distillation; (6) Thermal Diffussion; (7) Diffusion; (8) Electromagnetic Separation; and (9) Ultracentrifuges. Each of these parts is subdivided into chapters, one chapter comprising a paper. There are sixty-three papers in all, varying in number from two for ultracentrifuges to thirteen for electromagnetic separation.

In addition to about twenty excellent papers covering the theoretical aspects of the various separation processes, the results of investigations dealing with the separation of isotopes of specific elements are reported as follows: chemical exchange (which also includes ion-exchange, exchange distillation and gas chromatography)—nitrogen, boron, hydrogen, lithium, and sulfur; electromigration—lithium, magnesium, rubidium and sodium; distillation—oxygen, lithium, hydrogen and boron; thermal diffusion (including liquid thermal diffusion)—bromine, the inert gases, hydrogen, oxygen and uranium; gaseous diffusion (which includes isotope separation pumps and "sweep-diffusion")—neon, argon and uranium; the electromagnetic method (including the high-frequency mass spectrometer or "mass-filter")—numerous elements, with detailed reference to the heavy elements, radioisotopes and high-purity isotope collections; the ultracentrifuge—uranium. There is also a paper dealing with the use of a digital computer for the solution of an isotope-plant problem.

At the end of each full-length paper there is included a verbatim report of any discussion concerning the paper. There are included for easy reference an author index and an element index at the end of the volume. There seem to be very few typographical errors.

The volume certainly should serve as an excellent reference in the isotope separations field for years to come.

Lehrbuch der Kernphysik—Band 1, Experimentelle Verfahren

Edited by G. HERTZ (B. G. Teubner Verlagsgesellschaft, Leipzig, 1958, 228 pages, $3.50)

Atomic structure, nuclear radiations and particle accelerators are the subject matter of this volume. It should serve as a good introduction for the student or engineer who is new to the subject. The treatment is qualitative, using few tables or formulas. There is no indication of what subject matter is to follow in later volumes, but the set is off to a good start.—R. H. E.

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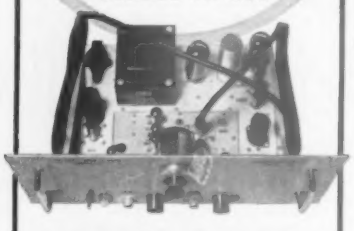

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LETTERS

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DEAR SIR:

In reference to Charles A. Pelletier's article, "Permissible Weight Concentrations for Enriched Uranium" (NU, Oct. '58, p. 111), I believe that the MPWC for natural uranium in air should be 72.2×10^{-6} μg/ml, vice 7.28×10^{-6} μg/ml, as stated. According to other sources,* the specific activity for natural uranium should be 7.02×10^{-7} μc/μg, vice 6.86×15^{-7} μc/μg, as listed. This would account for part of the difference, and the misplaced decimal point would account for the rest.

—WILLIAM A. BROBST
Health and Safety Division
U. S. Atomic Energy Commission
Chicago Operations Office
Lemont, Illinois

* Trilinear Chart of the Nuclides (revised July 1, 1958); Radiological Health Handbook, Jan. '57; Physics Standards, ANL-5800, 1958.

DEAR SIR:

My value of 7.28×10^{-6} μg/ml should read 7.28×10^{-5} μg/ml. This was a typographical error in the original manuscript.

The discrepancy between the two natural uranium specific activities is due to the use of different references. I do not think a difference of 2% is significant considering the purpose of the article.

—CHARLES A. PELLETIER
Bethlehem Steel Company
Bethlehem, Pennsylvania

The Whole Truth

DEAR SIR:

In your review of the papers presented in the "Nuclide Production" section of your second Geneva conference report (NU, Sept. '58, p. 88), the impression is given that the study of fluorine chemistry by means of fluorine-18 tracer is novel and is made possible by information first disclosed in the conference papers 937 and 1775.

To correct this impression: fluorine-18 has been produced routinely and has been available for purchase from the Hot Laboratory at Brookhaven since June, 1955. It has been so listed in "The Isotope Index." Not only has work been done with this nuclide at Brookhaven, but it has been shipped to laboratories as far away as Oak Ridge.

Paper 1775, "The Radioactive Isotope F^{18}: Preparation, Properties and Uses," by R. M. Adams, J. Sheft and J. J. Katz, ignores completely papers in the literature covering the work done on the production of fluorine-18 at Brookhaven. These papers include:

H. O. Banks, Preparation of fluorine-18, NUCLEONICS **13,** No. 12, 62 (1955).

L. G. Stang, W. D. Tucker, R. F. Doering, A. J. Weiss, M. W. Greene and H. O. Banks. "Development of Methods of Production of Certain Short-Lived Isotopes," Proceedings of the International Conference on Radioisotopes in Scientific Research, Paris, Sept. 1957, paper 190 [abstracted in *Nuclear Sci. Abstr.* **12,** 379 (1958)].

W. D. Tucker, M. W. Greene, A. J. Weiss and Alex Murrenhoff. "Methods of Preparation of Some Carrier-Free Radioisotopes, Involving Sorption on Alumina," Annual Meeting, American Nuclear Society, Los Angeles, June, 1958, paper 20-10.

You also state that "Both groups agree that the best method of production is neutron irradiation of an intimate mixture of LiF and Al_2O_3." Neither paper makes the claim that this is the "best" method, but merely that this was the method used. Actually, fluorine-18 can be prepared not only free from contaminating radioactivities but also carrier-free at least as easily and quickly by methods we have published as by any other.

—W. D. TUCKER
Radioisotope Development Section
Brookhaven National Laboratory
Upton, N. Y.

[EDITOR'S NOTE: If an erroneous impression of the novelty of F^{18} methods was created by our Geneva report, we hope that this letter and its bibliography will set the matter straight. An additional reference is R. B. Bernstein, J. J. Katz, Fluorine-18: preparation, properties, uses, NUCLEONICS **11,** No. 10, 46 (1953)].

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INDUSTRY NOTES

• **High Voltage Engineering** has developed a 6-Mev linear accelerator for medical therapy and research uses; sales price is $108,000. The machine has an X-ray output of 200 r/min at 100 cm, or, converted to electron output, will deliver up to 500 watts at energies from 2 to 7.5 Mev.

• **Magnesium fluoride slag** containing small amounts of normal uranium is now available from AEC at $26/kg contained U; the slag contains about 3% U in powder form.

• **Lakeview Mining,** Lakeview, Ore., has begun milling operations with its $3-million U-reduction plant. Capacity is 210 tons of ore daily, supplied from Lakeview's own mine and independently owned ore bodies.

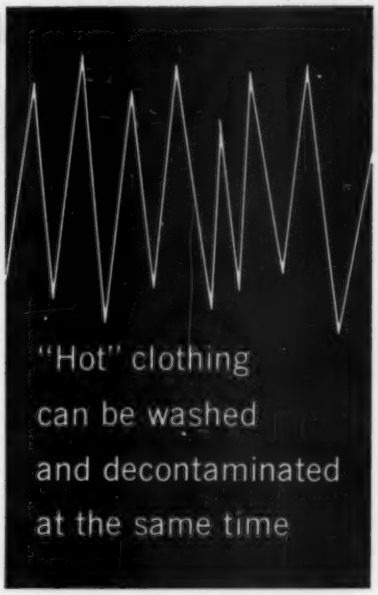
COMPANY EXPANSIONS. The research activities of **Cornell Aeronautical Laboratories,** Buffalo, have been expanded to include atomic energy; a nucleonics section headed by Arthur Hansen is studying protective measures associated with the Aircraft Nuclear Program and salient performance characteristics of a new reactor concept for educational use. . . . **Vard, Inc.,** Pasadena, a recent entrant into the nuclear field, is looking around Southern California for new acquisitions; John Swint, president and general manager, reported its new nuclear operations "have been especially rewarding."

NEW FIRMS. Wilfred R. Konneker, official of Nuclear Corp. of America, has purchased all assets of Nucor's medical division and will operate the division independently under the name **Nuclear Consultants Corp.** . . . **Geophysics Corp. of America** has been formed in Boston to provide research and development services in environmental physics; initial emphasis will be given radiation physics, among others.

NEW BUSINESS. **Panellit, Inc.,** Skokie, Ill., is building a $235,000 electronic control system for the Indian Point reactor of Consolidated Edison. . . . **Nuclear Science and Engineering** has a contract from the Air Research and Development Command for development of a low-level radioactivity counter to be used in a new quality-control system for transistor production. . . . **United Shoe Machinery** has contracts 1. to design and develop a fuel-handling system for replacing spent fuel elements of the Yankee reactor at Rowe, Mass., and 2. to design and build control-rod drive mechanisms for the prototype and ship reactor in the Navy's nuclear destroyer program. . . . Greece has purchased a subcritical training reactor from **Nuclear-Chicago** for installation at the Democritus Nuclear Center, near Athens. . . . **Vitro Laboratories** will investigate the chemistry of long-lived radioactive fission products under a contract from Phillips Petroleum. . . . Contracts covering construction of nearly 100 fuel elements have been awarded **Sylvania-Corning Nuclear Corp.** by Penn State Univ., Univ. of Florida and McMaster Univ. (Canada). . . . Reactor simulators have been delivered by **Leeds and Northrup** to the Pakistan AEC and by **Brown Instruments Div.,** Minneapolis-Honeywell, to Syracuse Univ. and the Univ. of Minnesota. . . . **Bailey Meter** has subcontracted the control instrumentation and safety systems for the Enrico Fermi reactor to **Stromberg-Carlson div.,** General Dynamics. Delivery is due in February, '60.

COMPANY MOVES. Expanding, **Radiochemistry, Inc.,** has moved to larger quarters at 1111 W. St. Catherine St., Louisville, Ky.; James E. Lewis has taken over as senior scientist, succeeding William H. Johnston. . . . New address for Britain's **Associated Electric Industries/John Thompson Nuclear Energy Co.** is 33 Grosvenor Place, London, S. W. 1.

FINANCIAL. A 2/1 stock split has been announced by Nuclear-Chicago, whose stock has more than tripled in price in the last year. . . . **General Dynamics** reported higher sales but lower earnings from 1957 for the first nine months 1958; its General Atomic div. reported "accelerated work" during the period on the high-temperature, gas-cooled reactor, which has since been proposed by Philadelphia Electric for construction on its grid. . . . **Varian Associates,** Palo Alto, Cal., reported a 61% increase in net income for the fiscal year ending Sept. 30 on a sales increase of only 16%; earnings were 90 cents per share, compared with 56 cents a year earlier.



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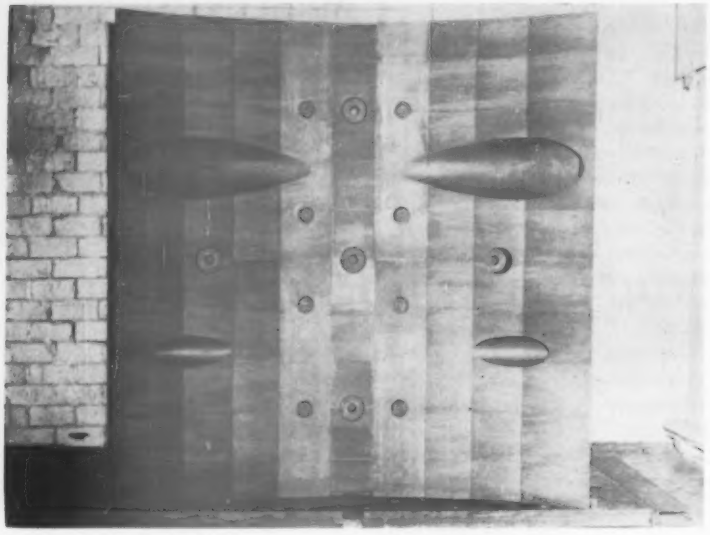

Precision Machining—Not Surrealistic Sculpture

Fifty tons of nuclear-grade graphite was assembled for the thermal column of the NRU reactor at Chalk River, Canada, with watch-like precision. Some 1,300 graphite blocks were fitted into place to form five distinct sections (one of which is shown above) with the outer face of the column, ~10 ft square, being held to a tolerance of −0.030 in. (the column extends ~11 ft from the reactor tank, or calandria). Section No. 1 is made up of 30 blocks. The other four sections have 144 blocks each. Of the total, only a few were duplicates. A tolerance of 0.010 in. was held in machining each block. Sections No. 1 and 2, whose curved faces nest within 1 in. of each other, have common bores of both a 12-in. and 6-in. hole through their entire width. As can be seen in the photograph of section No. 2, above, some of the many holes in the faces were bored at the junction of two blocks, others at the junction of four. All five sections have a number of holes of varying sizes that align to take straight, tapered and stepped graphite pins. Honeycombing the sections are countless holes for thermocouple leads.—National Carbon Co. Div., Union Carbide Corp., Niagara Falls, N. Y.

Box Furnace

Laboratory-type box furnace (above) is double-end, through-type furnace that permits materials to be cooled in protective atmosphere and has automatic temperature control by radiation detector. Heating chamber, lined with high-purity brick suitable for operation up to 3,200° F, is designed with throats at both ends to permit slow heating and cooling of charge.—General Electric Co., Shelbyville, Ind.

Neutron Dosimetry Service

Expanded neutron dosimetry service includes supplying standard and custom dosimeters and complete post-irradiation analysis. It also includes supplying bare and cadmium-covered cobalt foil and wire, as well as sulfur pellets, to provide dosimetry data for thermal, epithermal and fast neutrons.—Nuclear Science and Engineering Corp., Section 4-p, P. O. Box 10901, Pittsburgh 36, Pa.

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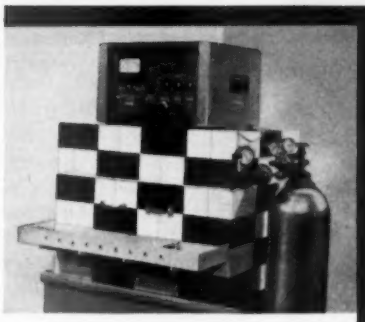

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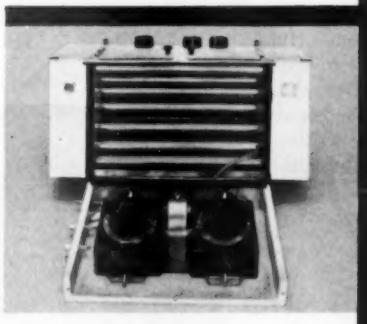

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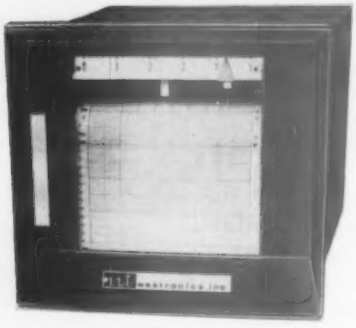

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- Limit switches
- Transmitting slidewires

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variety of output voltages and currents and for 60 cps, 400 cps or d-c inputs.—ERA Pacific, Inc., 1760 Standford St., Santa Monica, Calif.

Rotating-Mirror and -Drum Cameras

Rotating-mirror camera (above) records position-versus-time relationships, sweeping image from hypersonic object source onto fast-emulsion film strips. Heart of the unit is hexagonal, first surface mirror, rotating at 3,000 rps, which provides writing speed of 4 mm/μsec for total writing time of 50 μsec. Other components are cast-aluminum main housing, standard F/2.5 lens, two curved film holders and air turbine drive. Rotating-drum camera, in addition to making position-time film records, also can be used with densitometer for data of hypervelocity phenomena. In conjunction with Schlieren system, it will produce μsec-order photographic frames for graphical analysis. Dynamically balanced drum rotates at 600 rps for writing speed of 0.19 mm/μsec and total writing time of 1667 μsec.—Avco Manufacturing Corp., 201 Lowell St., Wilmington, Mass.

Constant Voltage Supply

Power supply provides stable, calibrated, d-c voltage without using standard cells or batteries. Stability is ±0.05% for ±20% supply voltage variations; it has ±0.08% maximum drift over 10,000 hr of operation (readjustable) and ±0.0015%/° C max. change in ambient temperature. Standard output is 1 v d-c at 2 ma into 500-ohm load. Other outputs are available.—The Hays Corp., Michigan City, Ind.

10-Mev, 21-kw Accelerator

Mark 20-J21 linear electron accelerator can be ganged into integrated systems operated by one person. Spare accelerator sections can be provided for use when principal sections are being serviced. Continually pumped vacuum systems have key components, even those in klystron, mounted by metal-gasketed bolted joints for ease of replacement. Mark 20-J21 produces 21 kw of electrons at 10 Mev or 10 kw of electrons at 17.5 Mev. At 10 Mev, accelerator can produce 6 kw of X-rays. With 10-Mev electrons, unit can irradiate uniformly (±25%) materials of unit density 1¼ in. thick. By cross-firing, 2¾-in. sections can be accommodated.—Applied Radiation Corp., 2404 North Main St., Walnut Creek, Calif.

Megatrometer

Designed for 14,000 to 5×10^{15}-ohm resistance measurements, portable Megatrometer features transistorized power supply and built-in calibration standard. It has accuracy of 3% at 10 megohms and handles test voltages in the range of 3–1,000 v.—Mid-Eastern Electronics, Inc., 32A Commerce St., Springfield, N. J.

Dual Count Ratemeter

Model LCRM-22-RH counting-rate meter simultaneously shows radioactivity in two body organs or areas and ratio or difference between them. Entire range of 50–50,000 cpm is measured without need of switching ranges.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Air Sampler

Aerosols are collected on high-efficiency filter at 1–3 cfm with volume of air and operating time recorded. Entire unit (above) is housed in weather-proof shelter and is designed for continuous operation.—Gelman Instrument Co., 233 Jefferson St., Chelsea, Mich.

20-μμf Capacitor

Vibrating capacitor requires no shock mounts and features over-all steel housing filled with inert gas and hermetically sealed. Magnetic driver unit is

mounted outside seal and is completely shielded from capacitor. Typical specifications include: insulation resistance of 10^{14} ohms; contact potential of <25 mv, positive or negative; drift of $<\pm 0.2$ mv in 24 hr at constant temperature, <0.4-mv change from 25–50° C, <10 mv in 1 yr; conversion efficiency of $<12\%$ ratio of a-c rms voltage output to d-c voltage applied at specified excitation; excitation voltage of 4 v rms 50–200 cps coil resistance 25 ohms.—Tracerlab Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Level Gage

Model 40104 continuous-level gage (above) measures level of liquids in totally enclosed containers of any size and dimensions with accuracy to a few hundredths of an inch. Continuous readings are provided in depth or volume.—Radiation Counter Laboratories, Inc., 5121 W. Grove, Skokie, Ill.

X-Ray Detector

Model 607-X is portable device that warns against over-exposure to X-rays. It operates over 100–600 kev energy level and is designed with specially constructed internal shielding so that it can make measurements in presence of high-intensity rf pulses or other types of electromagnetic, magnetic and electrical fields.—Universal Transistor Products Corp., Westbury, N. Y.

Recording Spectrometer

Model N-125OR is complete recording spectrometer including scintillation detector with lead shielding. Chart-drive motor is geared indirectly to remote base-line helipot and provides direct calibration of 10-in. chart in terms of energy. Specifications are as follows: energy range is 25 kev to 8 Mev (10 in.); long-time stability is 0.25%/day; linearity is $>1\%$; background count is <25 cpm with window open.—Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. J.

Photomultiplier Tube

Model 7264 is head-on type photomultiplier tube with typical pulse-height resolution of $\sim 8\%$. It includes semi-transparent photocathode on inner surface of spherical faceplate of tube, minimum photocathode diameter of 1.68 in., 14 electrostatically focused multiplying (dynode) stages and focusing electrode with external connection. Spectral response covers range of

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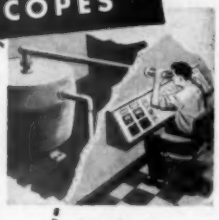

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~3,000–6,500 angstroms. When operated at supply voltage of 2,000 v, it has median luminous sensitivity of 875 amp/lumen and median current amplification of 12,500,000.—Radio Corporation of America, Harrison, N. J.

High-Vacuum Pump

Model H-32-P, 32-in. vacuum oil diffusion pump (above) has top speed above 50,000 cfm (24,000 liters/sec) at inlet pressure of 1×10^{-4} mm Hg and speeds above 30,000 cfm at pressures between 3.5×10^{-4} and 6×10^{-6} mm Hg. Untrapped blank-off is less than 1×10^{-6} mm Hg and tolerable forepressure <0.2 mm Hg Pump requires 10 kw of 220- or 440-v, 3ϕ, 60~ power and 6 gpm flow of water $<80°$ F. —NRC Equipment Corp., 160 Charlemont St., Newton Highlands 61, Mass.

Controlled-Heat Source

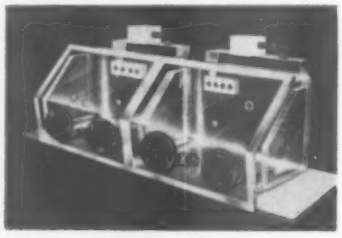
Plasmatron (above) was developed for creating and sustaining temperatures >22,000° F. System ejects controlled jet of electrically neutral, partially ionized gas, usually argon or air. Temperature at chamber orifice is sufficient for vaporizing any element known. Size of jet is up to ½ in. in diameter and 6 in. long. Systems have various power levels in the range 12.5–160 kw. —Giannini Plasmadyne Corp., 3839 S. Main St., Santa Ana, Calif.

DP Transmitter

Model 245 is bellows-actuated differential pressure transmitter available in standard ranges of 20–600 in. water differential.—The Hays Corp., Michigan City, Ind.

Scintillation Spectrometer

Spectrometer provides automatic histogram plotting of integral or differential spectra. Unit has step drive rather than continuous drive for baseline control and count integrator instead of ratemeter. Base line is advanced sequentially, in 1-v intervals, for up to 100 channels. Counting time at each setting can be selected from 0.5 to 8 min.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.



Tandem Dry Boxes

Model 40 Control/Lab (above) is portable, self-contained, 3 × 2 × 2-in. dry box specifically designed for use in tandem. Enclosure housings are available in transparent plastic, stainless steel or epoxy Fiberglas. Standard, front, observation glove panels are available that slide or can be opened and closed to and from hermetic state within seconds.—Controlled Atmosphere Enclosures Mfg. Co., Inc., 1061 E. 8th St., Jacksonville 6, Fla.

C^{14}-Labeled Compound

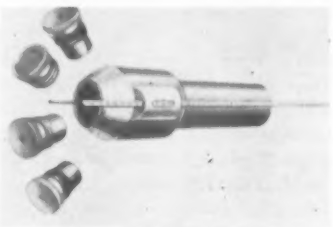
Doubly labeled *l*-methionine (methyl-$C^{14}D_3$) is regularly available at specific activity of 1 mc/millimole and is free of both chemical and radiochemical impurities. Radiochromatogram is furnished with each lot.—Research Specialities Co., 2005 Hopkins St., Berkeley 7, Calif.

Ultrasonic Cleaner

Model DR-250-AH ultrasonic cleaning unit has pulsing generator that delivers output of 1-kw peak power for high cavitation with low power consumption. Transducerized 5-gal stainless-steel tank has working dimensions of 14 × 10 × 9½ in.—Acoustica Associates, Inc., 26 Windsor Ave., Mineola, N. Y.

Electro-Optical Shutter

Exposure time of 0.01 μsec has been achieved with Kerr-cell (above) electro-optical shutter. Complete shutter includes pulse generator and specially designed spark gap. Unit operates from external 0–50 kv power supply and low-voltage trigger source. Electric field needed to produce phase rotation of electromagnetic light vector as it passes through nitrobenzene-filled cell lies between 10 and 15 kv/cm. Thus, pulse generator for 5-cm aperture must deliver 50–75 kv to Kerr cell plates. Exposure time can be accurately varied from 0.01 to 1 μsec. Wave form of exposure characteristic is nearly that of square wave.—Avco Manufacturing Corp., 201 Lowell St., Wilmington, Mass.



Scintillation Counter

Transistorized scintillation counter (above) includes five interchangeable collimators. Among these is "A" filter with $\frac{1}{16}$-in. lead shield to replace plate-type filter. Removable, sliding variable spacer is calibrated in centimeters.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Vapor-Phase Counter

Model VPC-1 vapor-phase internal-flow counter for gas chromatography can do radioassay and mass assay of gas compounds simultaneously. It permits various gas fractions tagged with tritium or carbon-14 to be separated during radioassay and mass assay without conversion to standard counting forms. Complete radioactivity spectrum can be obtained, thus decreasing chances of missing portions of activity present in unexpected chemical forms. Radioactivity in amounts as small as 10^{-9} c is readily detected and resolved. Designed to operate at temperatures up to 200° C, four models are available for 4, 12, 36 or 100-cm³ volumes.—Technical Measurement Corp., 140 State St., New Haven, Conn.

Leak Detector

Model 24-110A electronic leak detector (above) is special-type mass spectrometer "focused" on mass 4 (helium). With system pressure below 0.05 microns, and sensitivity valve in closed position, leak rate of 2×10^{-10} atm cm³/sec of helium will produce 5% of full-scale reading. Same leak rate will pass $<1 \times 10^{-10}$ atm cm³/sec of air.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Zirconium Hydride

MHI Grade R high-purity zirconium hydride contains <0.01% hafnium. It can be mixed with other powders and compacted. Equilibrium dissociation pressure is <1 atm at 900° C.—Metal Hydrides Incorporated, Congress St., Beverly, Mass.

Counter Simulator

Pulse source provides recurrent, exponentially shaped voltage pulses simulating output of gas-filled particle counter tube. Pulse rate is adjustable over a range of 1–15 pps, with voltage adjustable from zero to 100 mv.—Automation Dynamics Corp., 255 County Rd., Tenafly, N. J.

Pulse-Height Analyzer

Model PHA-2 pulse-height analyzer is capable of operating at counting rates >1,000,000 cpm without appreciable data distortion. Input amplitude range normally covered is 0–85 v positive. It is supplied with ten-turn, continuous controls for window-level (0–100% of range) and window-width (0–10% of range) adjustments.—Tullamore Electronics Laboratory, 6055 S. Ashland Ave., Chicago 36, Ill.

LITERATURE AVAILABLE

Light sources, radioisotope-excited, are described in 4-p. Bulletin 30.30.—United States Radium Corp., Morristown, N. J.

Tritium urinalysis service is given price schedule.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Standardized biological-shielding development to reduce cost of radiation shielding is described in literature.—Sumner Sollitt Co., 307 N. Michigan Ave., Chicago 1, Ill.

"Alloy Sheet and Light-Plate Fabrication" is short title of 30-p. booklet describing complex and unusual products and equipment.—S. Blickman, Inc., 8400 Gregory Ave., Weehawken, N. J.

Cockroft-Walton accelerators, positive-ion, are discussed in 6-p. bulletin.—Applied Radiation Corp., 1210 Springbrook Rd., Walnut Creek, Calif.

Reinforced-concrete cutting equipment and accessories are listed in catalog.—Truco Masonry Drilling Div., Wheel Trueing Tool Co., 3200-313 W. Davison Ave., Detroit 38, Mich.

Electrometer is described in 4-p. Bulletin 131.—Applied Physics Corp., 2724 S. Peck Rd., Monrovia, Calif.

Single-channel analyzer for scintillation spectroscopy is subject of 6-p. manual.—Wm. B. Johnson & Associates, P. O. Box 415, Mountain Lakes, N. J.

Nondestructive testing is subject of periodical "SS News."—Solus-Schall, Ltd., 15–18 Clipstone St., Great Portland Street, London W1, England.

Melting points and densities of metals are shown on two charts.—Fansteel Metallurgical Corp., North Chicago, Ill.

Nuclear Instrumentation is described in five bulletins.—BJ Electronics Div., Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.

Microwave spectroscopy is discussed in 8-p. bulletin.—Laboratory for Electronics, Inc., 75 Pitts St., Boston, Mass.

Plastic flours is subject of 4-p. booklet.—Cadillac Plastic & Chemical Co., 15111 Second Ave., Detroit 3, Mich.

"Engineering News" is title of external house organ published periodically.—Fenn Manufacturing Co., Newington, Conn.

Radiological laboratory for textile research is depicted in 4-p. folder.—North Carolina State College, Raleigh, N. C.

Hand and clothing monitor is described in 6-p. brochure.—E. M. I. Electronics, Ltd., Hayes, Middlesex, England.

Photographic plates and films for autoradiography, spectrum analysis and spectroscopy, and nuclear tracking are given Data Sheets Z3-129, -130 and -131, respectively.—Eastman Kodak Co., Rochester 4, N. Y.

Activation analysis is subject of No. 11 of "Radioactivity at Work."—Nuclear Science and Engineering Corp., P. O. Box 10901, Pittsburgh 36, Pa.

Data-processing system is described in 6-p. Bulletin 3017.—Beckman Instruments, Inc., 325 N. Muller Ave., Anaheim, Calif.

Nuclear magnetic resonance analyzer application to measurement of oil and water in geological cores (sand and dolomite) is described in 3-p. Report 9.58.—Schlumberger Well Surveying Corp., Ridgefield, Conn.

Polyethylene and its application in radioisotope laboratories is discussed

in external house organ "Plastics Weldor and Fabricator."—American Agile Corp., 5461 Dunham Rd., Maple Heights, Ohio.

Zinc-bromide window that is copper lined is described in 2-p. data sheet.—Research Equipment Co., P. O. Box 127, Glen Ellyn, Ill.

"Atomic Laboratory," name of set of instruments and accessories for educational purposes, is listed in 2-p. Bulletin N-7.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

"Tech Topics," external house organ, is published periodically.—Cook Electric Co., 2700 N. Southport Ave., Chicago 14, Ill.

Coincidence circuit, fast-slow, is described in 2-p. Bulletin 58-120.—BJ Electronics Div., Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.

"Photomultiplier Tubes" is title of 9-p. reprint.—E. M. I. Electronics, Ltd., Hayes, Middlesex, England (U. S. distributor: H. L. Hoffman & Co., Inc., 35 Old Country Rd., Westbury, N. Y.)

"Chemical Engineering" is title of 6-p. brochure.—Burns and Roe, Inc., 160 W. Broadway, New York 13, N. Y.

Radioactive absorbers, consisting of 24 lead and aluminum disks, are described in specification sheet.—Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

Radiation-source technology is discussed in "RAI Views and Previews," external house organ published periodically.—Radiation Applications, Inc., 370 Lexington Ave., New York 17, N. Y.

Radiation-protection equipment and clothing are listed in 2-p. catalog.—Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y.

Safety equipment and accessories are cataloged in 8-p. Bulletin N-35.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

"Ideas In Action" is title of 36-p. booklet on petroleum research and engineering.—Esso Research and Engineering Co., 15 W. 51st St., New York 19, N. Y.

Soft-beta counting by liquid-phosphor technique is discussed in 11-p. Bulletin 214B.—Technical Measurement Corp., 140 State St., New Haven, Conn.

"Pioneer in Stainless Steel" is title of 16-p. brochure describing manufacturing facilities.—Cooper Alloy Corp., Hillside, N. J.

Nuclear-equipment design, consultation and manufacturing activities are depicted in 95-p. brochure.—Ateliers de Constructions Electriques de Charleroi, Rue Vital Francoisse, Marcinelle-Charleroi, Belgium.

"Custom Steel Makers" is short title of 24-p. brochure on production of steel forgings and super-alloy steel products.—Midvale-Heppenstall Co., Dept. S-17, Nicetown, Philadelphia, Pa.

Fast-neutron detector is described in 2-p Bulletin 15.—Nuclear Enterprises, Ltd., 1750 Pembina Hwy, Winnipeg 9, Canada.

Scintillation detectors are listed in 2-p. Bulletin S-300-1.—Crystals, Inc., 123 Woodland Ave., Westwood, N. J.

"Vapor-Phase Chromatography" is title of 4-p. reprint.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Reactor components of Sinterwrought materials are described in loose-leaf folder.—Sintercast Corp. of America, 134 Woodworth Ave., Yonkers, N. Y.

Liquid-metal systems, inert-gas purifiers and furnaces with ultra-high-purity inert atmospheres are subjects of bulletin.—Liquid Metals, Inc., P. O. Box 266, Westford, Mass.

Lithium hydride is discussed in 4-p. Bulletin 102.—Foote Mineral Co., 18 W. Chelten Ave., Philadelphia 44, Pa.

"Titanium Tubing and Pipe" is title of 5-p. bulletin.—The Carpenter Steel Co., Union, N. J.

Research and development and manufacturing facilities and personnel are depicted in 36-p. brochure.—U. S. Industries, Inc., 6201 W. 63rd St., Chicago 38, Ill.

Nuclear instruments are shown in condensed catalog.—Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. J.

Binary scaler for use with medical isotope systems is described in 2-p. Bulletin BS-512.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Sprayed coatings for metals and ceramics, with possible nuclear applications, are discussed in literature.—Metallizing Engineering Co., Inc., Westbury, N. Y.

High-voltage power supply for spectrometry is discussed in "Tracerlog."—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Microfiltration, analytical and process, in submicron particle range is subject of brochure.—Millipore Filter Corp., 36 Pleasant St., Watertown 72, Mass.

Mass spectrometers are discussed in 16-p. Bulletin 1824C.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Closed-circuit television is subject of 12-p. Bulletin 2239.—Diamond Power Specialty Corp., Dept. PW, P. O. Box 415, Lancaster, Ohio.

Pneumatic pressure regulator, automatically operated and remotely controlled, is depicted in 4-p. brochure.—Marotta Valve Corp., Boonton Ave., Boonton, N. J.

Stainless-steel uses are discussed in 30-p. booklet.—Allegheny Ludlum Steel Corp., Oliver Building, Pittsburgh 22, Pa.

Magnetic flowmeter is described in 4-p. Specification 10D1416.—Fischer & Porter Co., 787 Jacksonville Rd., Hatboro, Pa. (in Canada: Fischer & Porter, Ltd., 2700 Jane St., Toronto 15, Ontario).

Carbon-14 and deuterium labeled compounds are given price lists.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

NUCLEAR CAMPUS

• **Union College** has installed a 1,120-curie, cobalt-60 source in a special building on its campus—the gift of Schenectady Varnish Co. for the joint use of the college and the company.

• **Oregon State College** has completed installation of an AGN-201 teaching reactor purchased from Aerojet-General Nucleonics.

• **California Institute of Technology,** with the help of a $1,165,700 grant from the Alfred P. Sloan Foundation, will build a five-story laboratory (two below ground level) for mathematics and physics research. The below-ground area will house a 10-Mev Van de Graaff accelerator purchased from High Voltage Engineering under a $1,000,000 grant from the Office of Naval Research. Cal Tech has also purchased a subcritical reactor.

• **Wayne State Univ.'s** subcritical, "pickle-barrel" reactor has just gone into operation. The unit is student-built, operates on 4,000 lb of natural uranium furnished by AEC in the form of aluminum-clad fuel elements. Other nuclear equipment on the campus: a rolling mill for the study of fabricating radioactive metals, an X-ray machine, a reactor simulator and a liquid-metal loop.

• **Fisk Univ.** has been elected as the 37th sponsoring university for ORINS. The election took place at the ORINS Council's 14th annual meeting on Oct. 21, where final plans were announced for construction of permanent headquarters at Oak Ridge; completion is due in the fall of 1959.

Courses

A three-day course in **scintiscanning** is being offered by ORINS Jan. 14–16—an advanced review of the basic techniques applied to the problems of radiation scanning. Contact William D. Jones, medical div., ORINS, P. O. Box 117, Oak Ridge, Tenn.

The Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service is offering "**basic radiological health**" Jan. 12–23 and "**environmental health aspects of nuclear reactor operations**" March 16–25. Contact chief, training program, 4676 Columbia Parkway, Cincinnati 16, or any USPHS regional office director.

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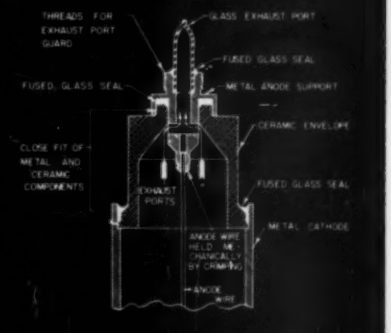

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(Additional Employment Opportunity Advertising on pages 116 & 117)

NEWSMAKERS

Engineer-biologist **John W. Baum** has been named supervisor of health physics in safety services, Allis-Chalmers. He will coordinate the general safety program at the Greendale Laboratories and specialize in safety aspects of A-C's nuclear power work.

New manager of manufacturing in General Electric's atomic power equipment dept. is **J. Robert Wolcott,** former manager of design engineering. He succeeds **John M. Hobbs,** who has joined GE's manufacturing services organization in New York City. Wolcott managed design of three plutonium reactors at the Hanford Works before taking charge of design-engineering in APED.

Wolcott

Three physicists, a chemical engineer and a visiting British physicist have joined the staff of General Atomic's John Jay Hopkins Laboratory. Respectively, they are: **Burton E. Freeman,** Los Alamos Scientific Laboratory; **Melvin Cutler,** Hughes Aircraft Co.; **Wallace E. Johnson,** Univ. of California's Los Alamos Laboratory; **William T. Furgerson,** Oak Ridge; and **Ronald F. Stebbings,** who is on a year's leave from University College, London.

Tracerlab has appointed **Edward J. Kraus,** formerly of R. S. Pettigrew Co., to industrial engineer for New England.

Eugene M. Zuckert, former member of AEC, has been elected board chairman of Nuclear Science and Engineering Corp. He succeeds the late Gordon Dean. An attorney and nuclear consultant in Washington, D. C., Zuckert has been a director of NSEC since June, 1957. He is also a director of AMF Atomics, Inc. (Canada). Zuckert was an AEC member from 1952 until he entered private practice in 1954.

Zuckert

Technical Measurement Corp. has named **Donald S. Davidson** chief engineer, responsible for completion of a new line of transistorized instruments. Davidson joined the firm from Knolls Atomic Power Laboratory.

John M. Walker has taken over as controller for Metals & Controls Corp., parent firm of M & C Nuclear.

W. A Higinbotham, chief of the instrumentation div., Brookhaven National Laboratory, has been named a Fellow of the Institute of Radio Engineers for "contributions to pulse circuits and nuclear instrumentation."

New general manager of the electronic components div., Anton Electronic Laboratories, Inc., is **Arthur Van Gordon.** He has been directed to incorporate the procedures for reliability and quality control in the component division that have been "so successfully achieved" in Anton's nucleonics operations.

Management changes at Leeds & Northrup include: **Nathan Cohn** has filled a new post—vice president for technical affairs; **Donald E. Moat** has been elected vice president for marketing; and **John F. Quereau** has been elected vice president for manufacturing.

J. W. Talbott has been selected to direct the engineering operations of the fuels preparation dept. at Hanford Works, operated for AEC by General Electric. He succeeds **P. H. Reinker,** now a consultant in GE's engineering services, New York City. Talbott had been manager for design and projects in FPD and, most recently, had been acting manager for engineering.

Talbott

John V. Dunworth, head of the reactor div. at Britain's Harwell research installation, has been promoted to assistant director at Harwell under **B. F. J. Schonland.**

At AEC's Savannah River Plant **Howard L. Kilburn** is the new deputy manager, succeeding the late **Winston Davis; Nathaniel Stetson** has been named director, technical and production div., succeeding Kilburn.

NUCLEAR CALENDAR

Jan. 26–29—10th Plant Maintenance and Engineering Conference, Cleveland (*Public Auditorium*). Nuclear session on maintenance in nuclear plants, Jan. 27. Contact Banner & Greif, 369 Lexington Ave., New York 17.

Jan. 28–29—First International Symposium on Nuclear Fuel Elements, Columbia Univ., New York. Sponsored jointly by Columbia and Sylvania-Corning Nuclear Corp. Contact H. H. Hausner, 730 Fifth Ave., New York 19.

Jan. 28–31—American Physical Society meeting, New York City (New Yorker). Contact APS, Upton, L. I., N. Y.

Mar. 31–Apr. 1–2—21st American Power Conference, Chicago (*Sherman*). Contact R. A. Budenholzer, Mechanical Engineering Dept., Illinois Institute of Technology, 3300 Federal St., Chicago 16.

March 31–Apr. 2—Symposium on millimeter waves, sponsored by the Defense Dept.'s research agencies and the Institute of Radio Engineers, New York City (*Engineering Societies Bldg.*). Contact Jerome Fox, Brooklyn Polytechnic Institute, 55 Johnson St., Brooklyn.

April 5–10—5th Nuclear Congress and Atom Fair, Cleveland (*Public Auditorium*). Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.

May 6–8—1959 Electronic Components Conference, sponsored by Institute of Radio Engineers, American Institute of Electrical Engineers, Electronic Industries Assoc. and West Coast Electronic Manufacturers Assoc., Philadelphia (*Benjamin Franklin*). Papers on instrumentation and control devices and radiation effects. Contact Bernard Osbahr, Electronic Industries, Chestnut & 56th Sts., Philadelphia 39.

May 30–June 5—5th World Petroleum Congress and Symposium on Applications of Atomic Energy to the Petroleum Industry, sponsored by the Permanent Council of the World Petroleum Congress, New York City. Contact C. E. Davis, gen. secy., 5th WPC, 527 Madison Ave., New York 22.

June 8–11—American Rocket Society semiannual meeting, San Diego. Session on nuclear propulsion. Contact Stan Gunn, Rocketdyne, 6633 Canoga Park Ave., Canoga Park, Calif.

June 15–17—Annual meeting of the American Nuclear Society, Gatlinburg, Tenn. Contact Octave J. DuTemple, John Crerar Library, 86 E. Randolph St., Chicago 1.

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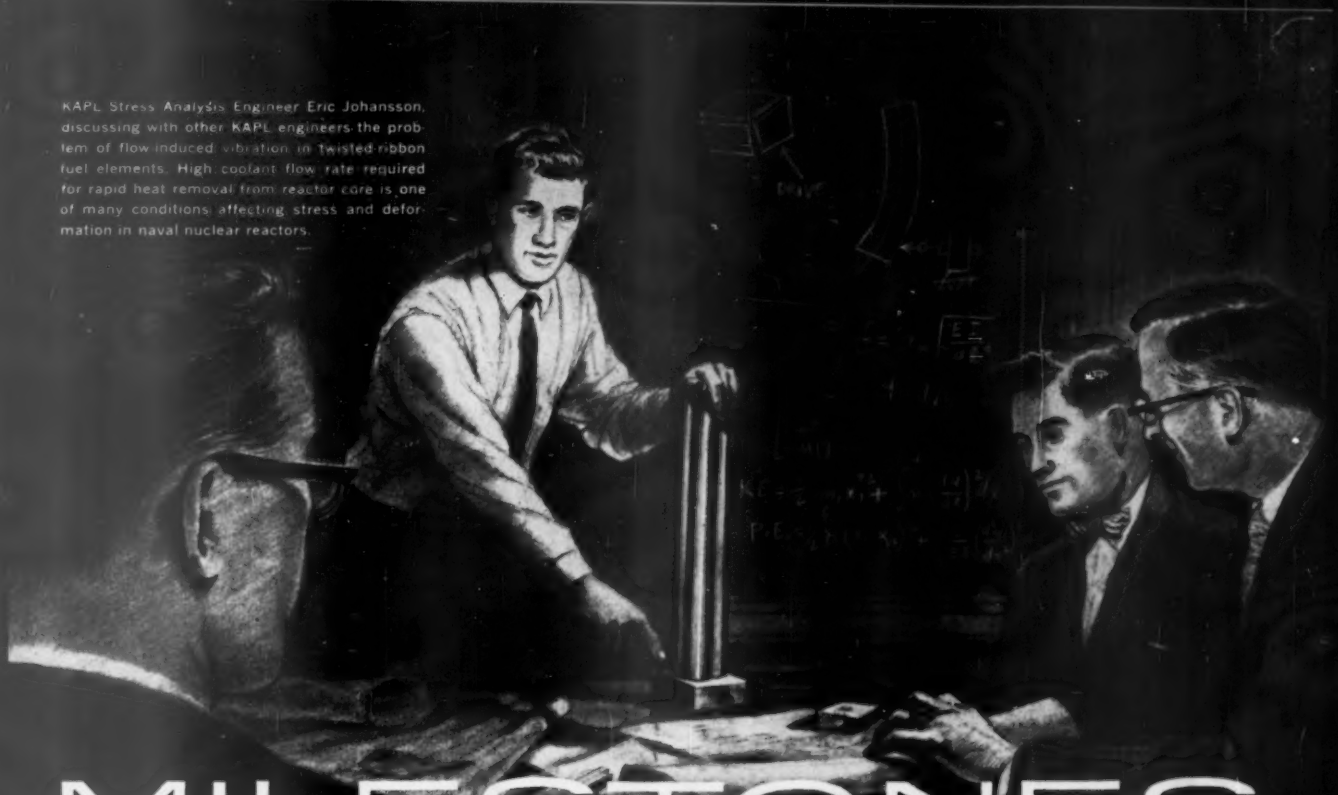

KAPL Stress Analysis Engineer Eric Johansson, discussing with other KAPL engineers the problem of flow-induced vibration in twisted-ribbon fuel elements. High coolant flow rate required for rapid heat removal from reactor core is one of many conditions affecting stress and deformation in naval nuclear reactors.

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Eric B. Johansson is one of approximately twenty Stress Analysis Engineers working on naval reactors at KAPL. Eric joined G.E. in 1951 following graduation from the California Institute of Technology and graduate study at UCLA. He has completed advanced study in engineering analysis as a graduate of G.E.'s Advanced Engineering Program and has taken additional graduate work at Rensselaer Institute of Technology under G.E.'s Tuition Refund Program.

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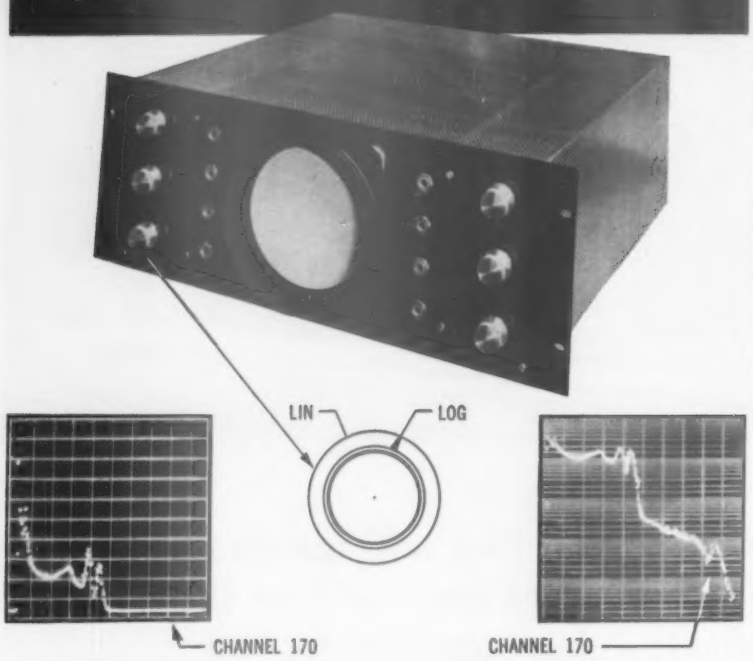

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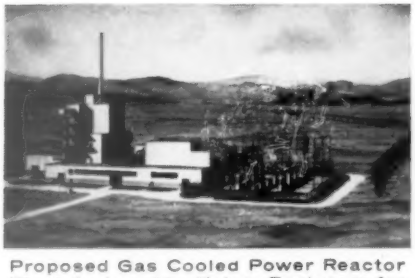

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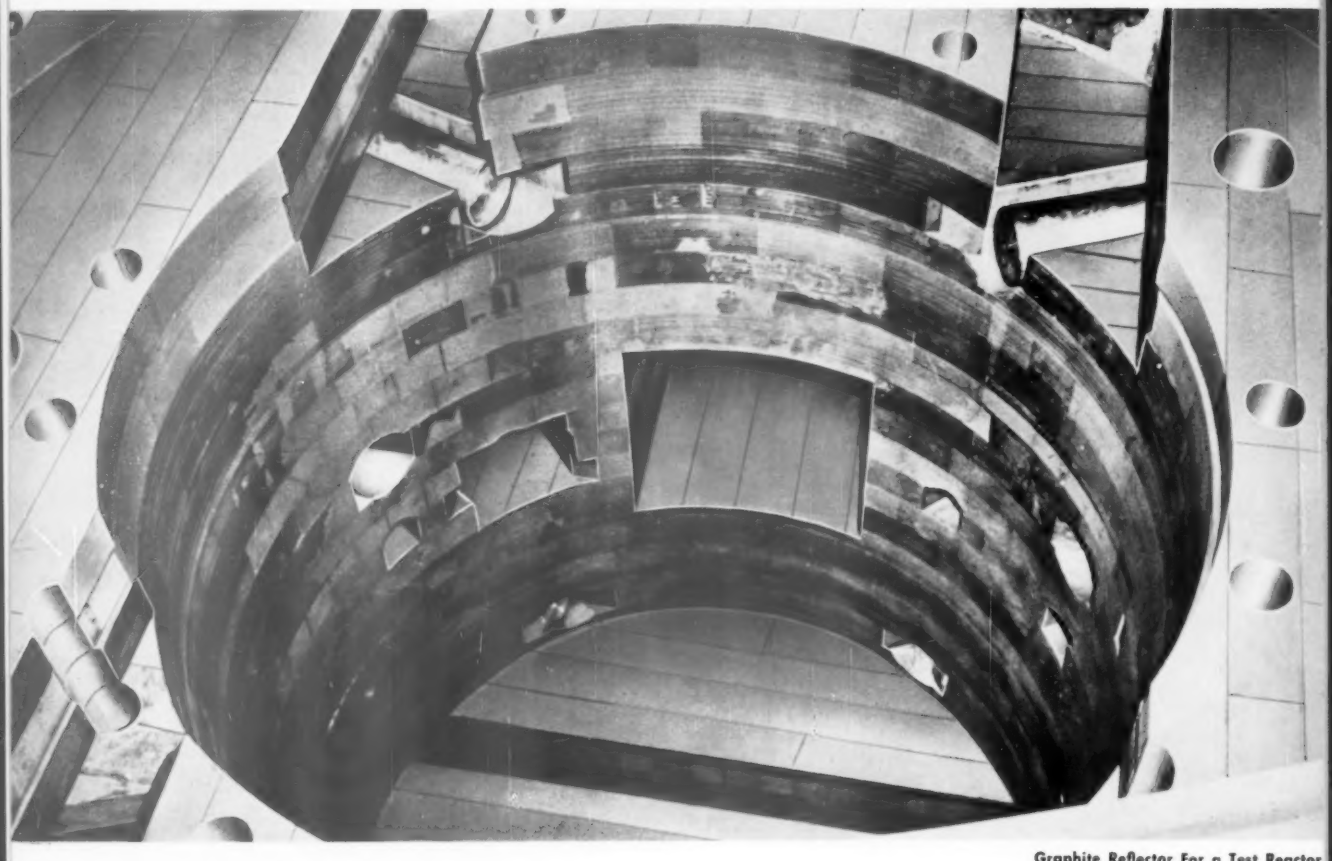

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Macroscopic absorption cross section ($cm^{-1} \times 10^5$)	38.30	33.67
Macroscopic scattering cross section (cm^{-1})	0.432	0.432
Average logarithmic energy decrement per collision	0.158	0.158
SLOWING DOWN POWER	0.0684	0.0684
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